



US009312888B2

(12) **United States Patent**  
**Weissman et al.**

(10) **Patent No.:** **US 9,312,888 B2**  
(45) **Date of Patent:** **Apr. 12, 2016**

(54) **ANTENNA INTERFACE CIRCUITS FOR CARRIER AGGREGATION ON MULTIPLE ANTENNAS**

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 279 days.

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(21) Appl. No.: **13/649,965**

(22) Filed: **Oct. 11, 2012**

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(65) **Prior Publication Data**

US 2014/0003300 A1 Jan. 2, 2014

**Related U.S. Application Data**

(60) Provisional application No. 61/666,088, filed on Jun. 29, 2012.

(51) **Int. Cl.**  
**H04B 7/04** (2006.01)  
**H04B 1/00** (2006.01)

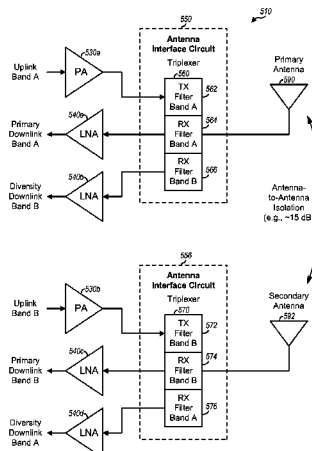
(52) **U.S. Cl.**  
CPC ..... **H04B 1/0064** (2013.01); **H04B 7/0404** (2013.01)

(58) **Field of Classification Search**  
USPC ..... 370/334; 455/13.3; 375/260–267  
See application file for complete search history.

(57) **ABSTRACT**

Techniques for supporting data transmission and reception on multiple bands for carrier aggregation are disclosed. In an exemplary design, an apparatus (e.g., a wireless device) includes first and second antenna interface circuits coupled to first and second antennas, respectively. The first antenna interface circuit includes a first transmit (TX) filter for a first band, which may be part of a first triplexer or duplexer. The first TX filter filters a first radio frequency (RF) signal prior to transmission via the first antenna. The second antenna interface circuit includes a second TX filter for a second band, which may be part of a second triplexer or duplexer. The second TX filter filters a second RF signal prior to transmission via the second antenna. The first and second RF signals may be transmitted simultaneously on the first and second bands for carrier aggregation.

**27 Claims, 20 Drawing Sheets**



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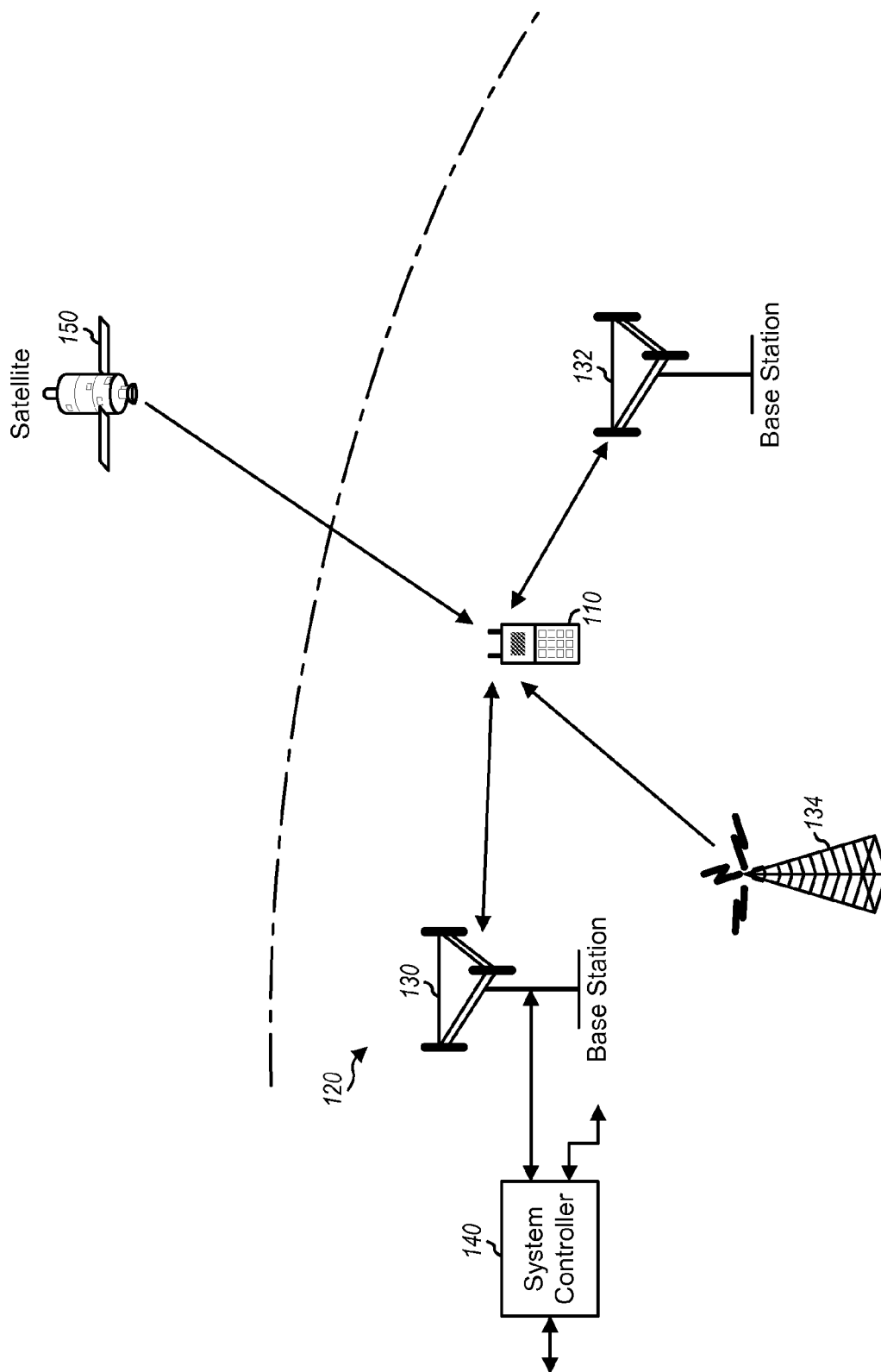
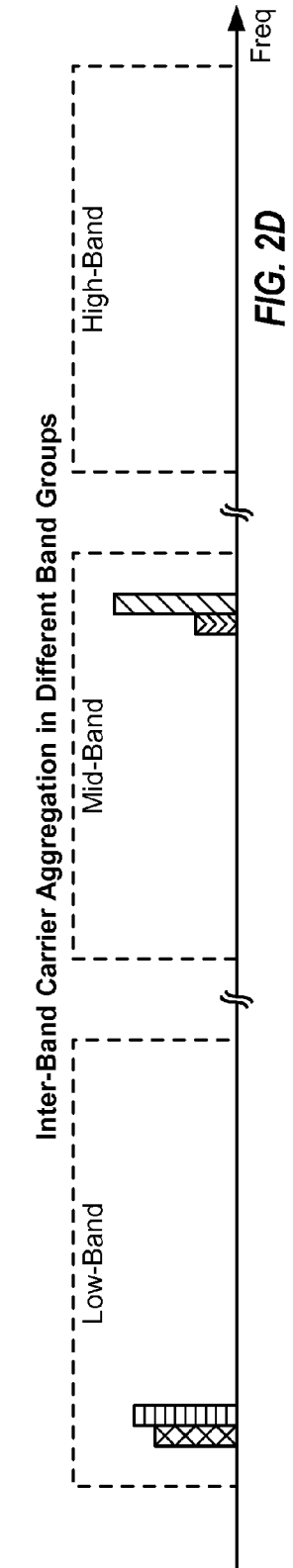
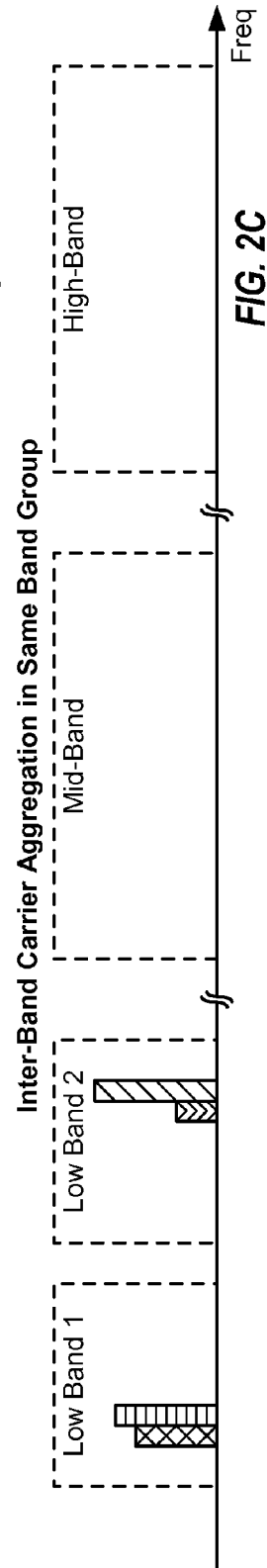
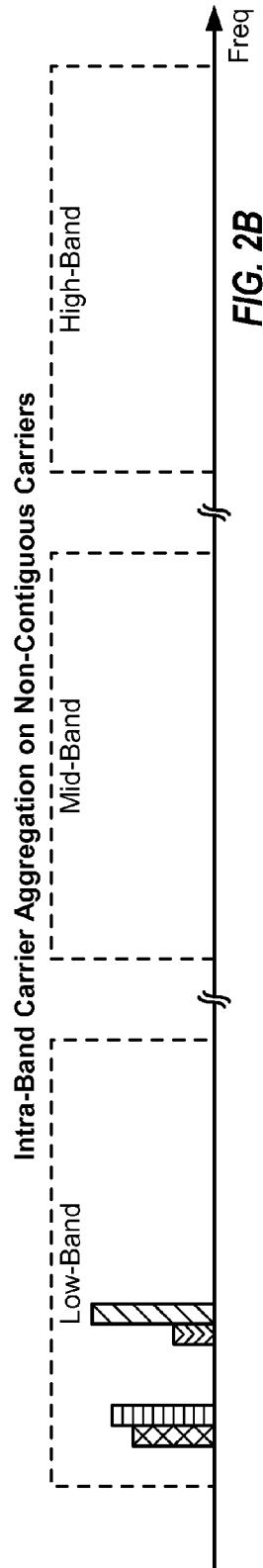
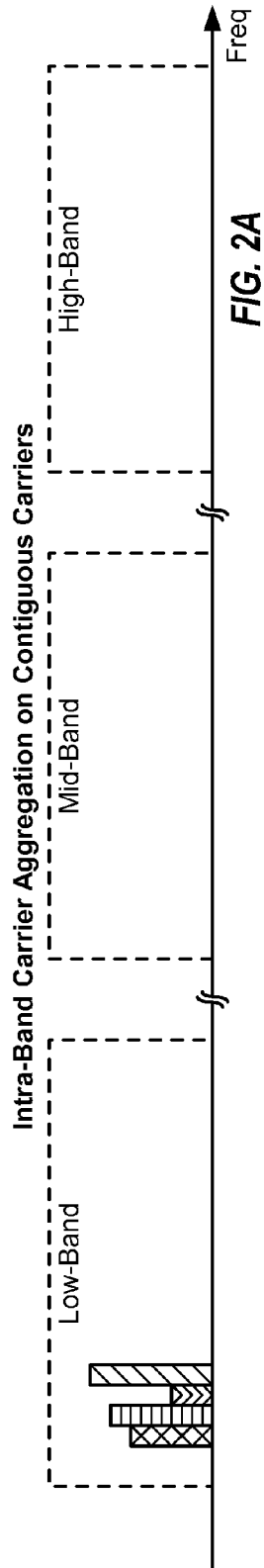
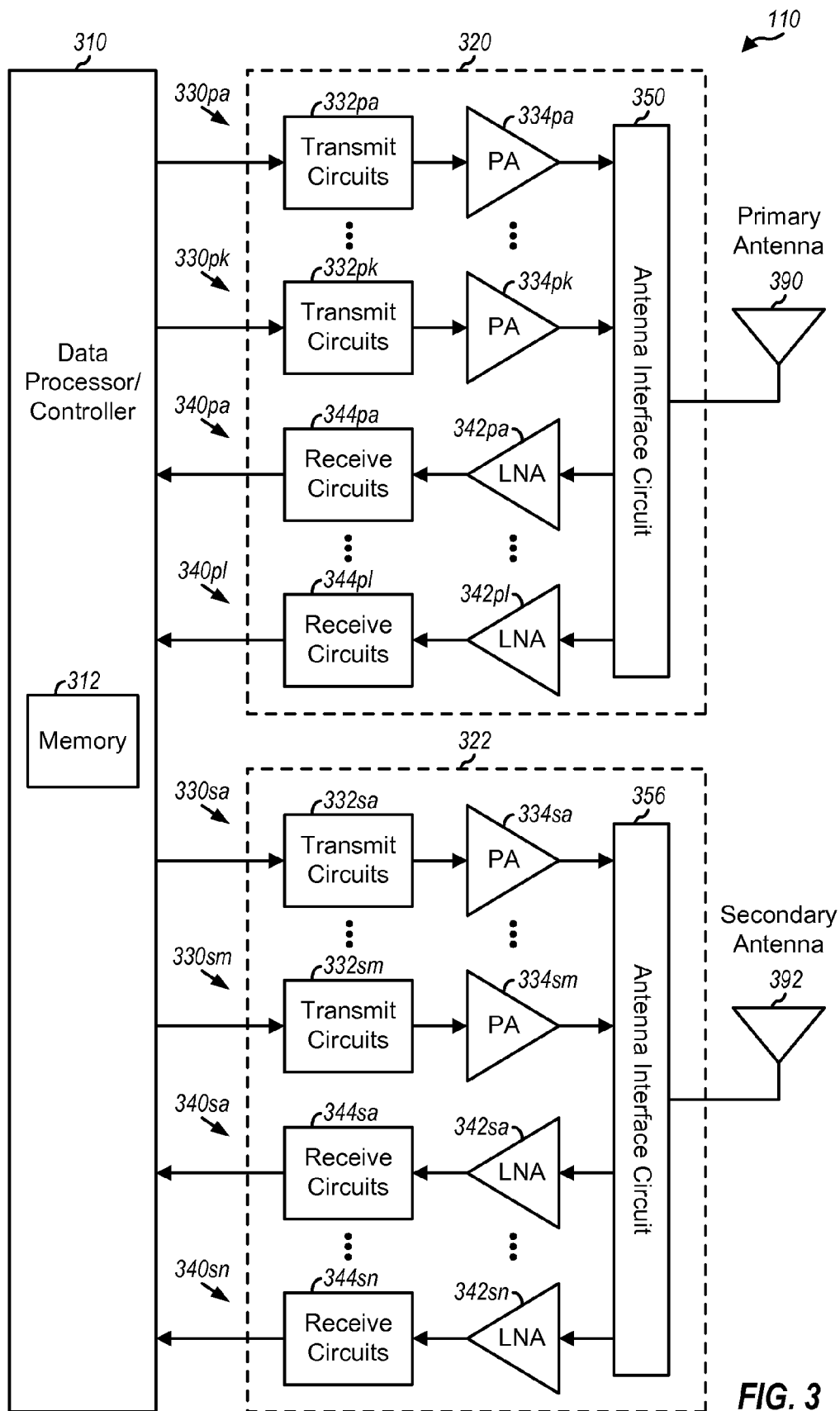


FIG. 1





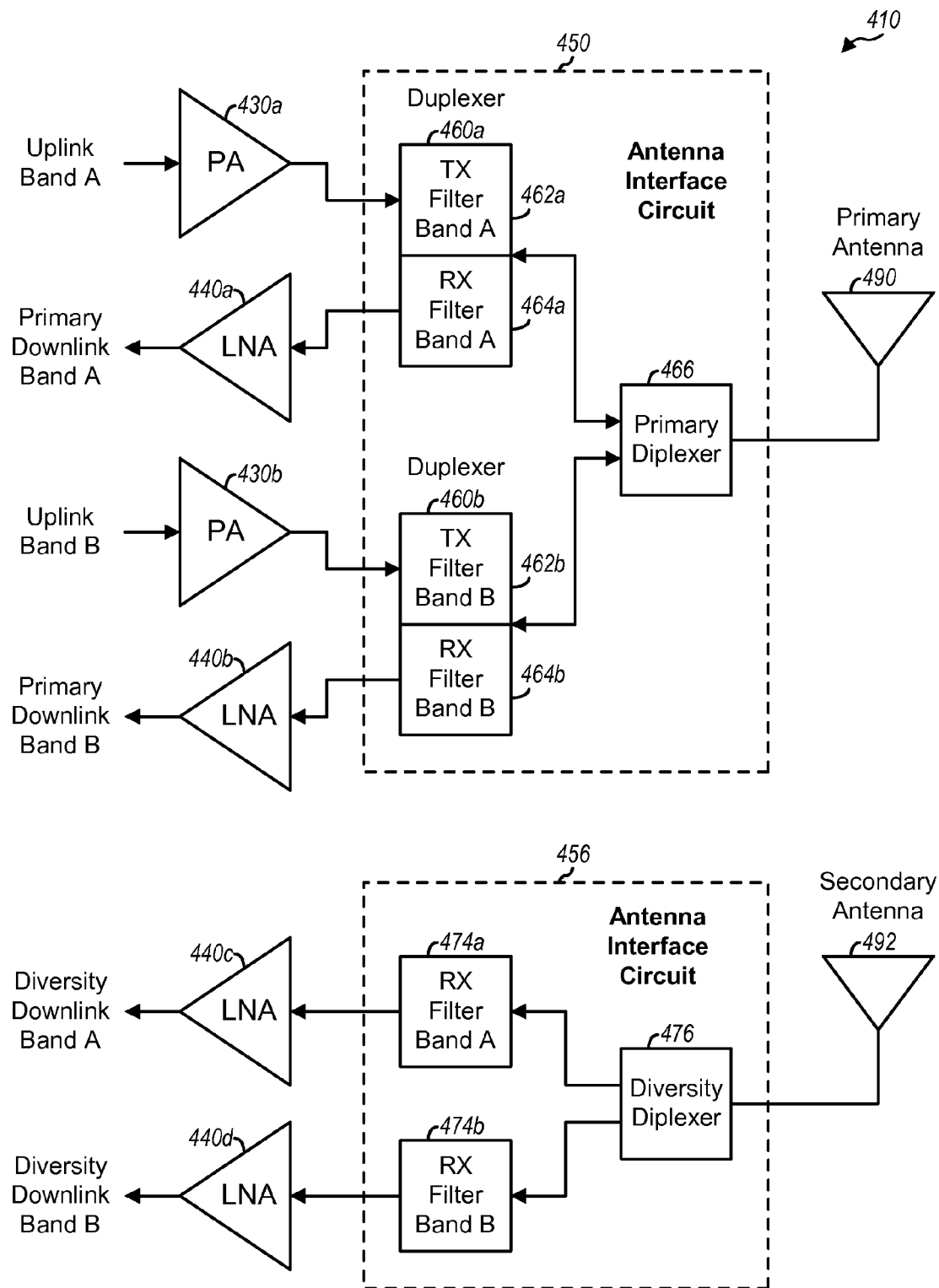


FIG. 4A

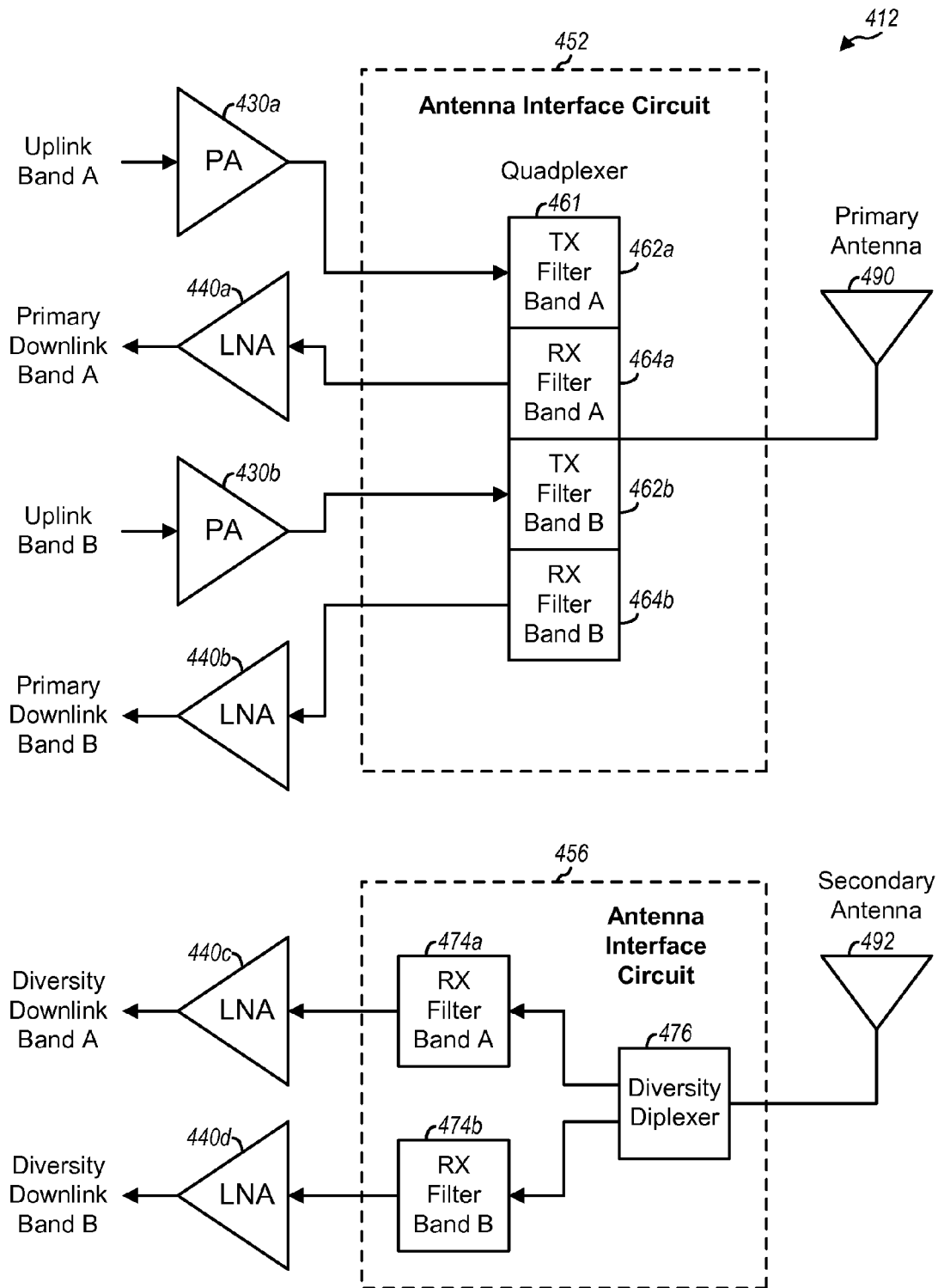
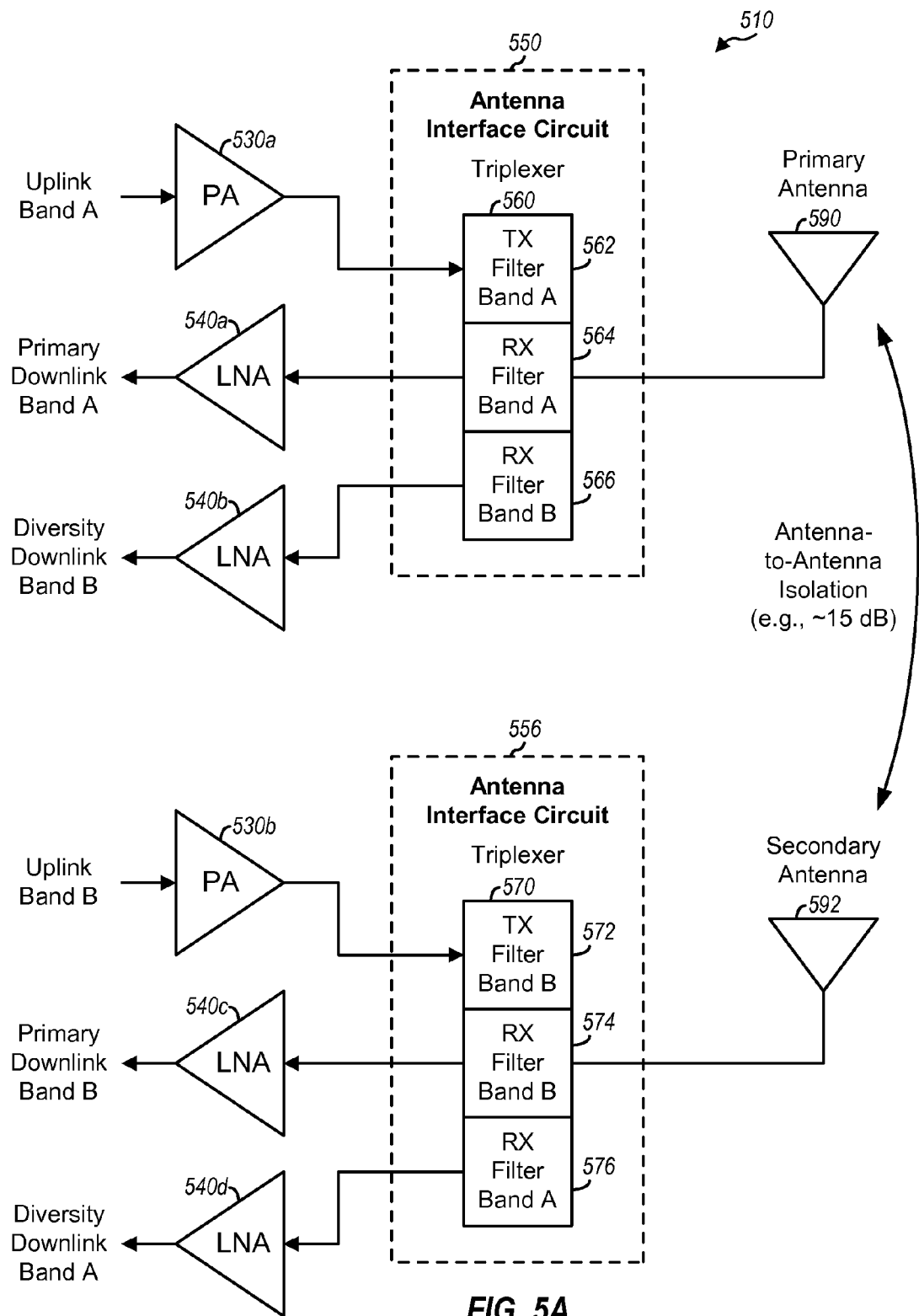
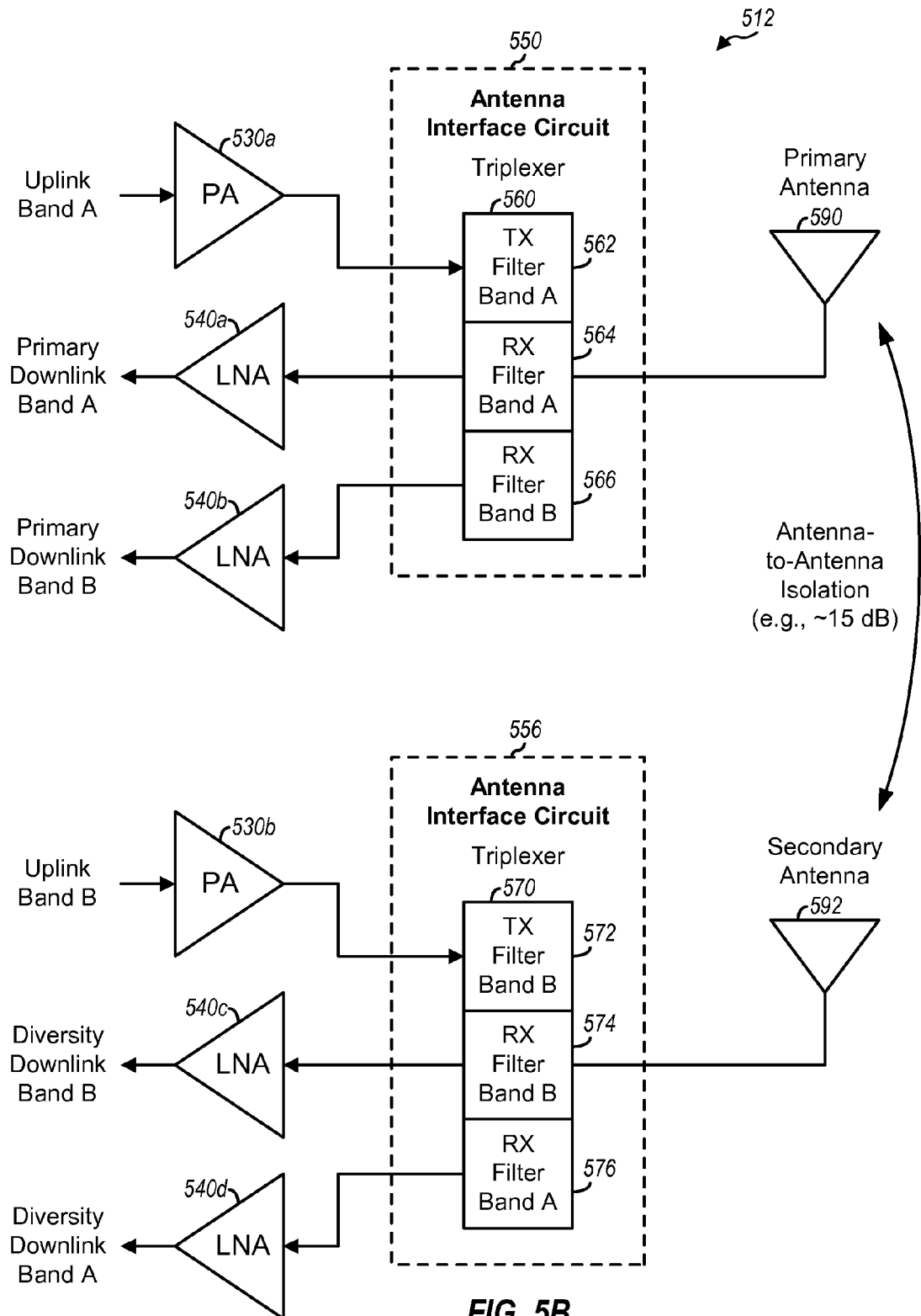
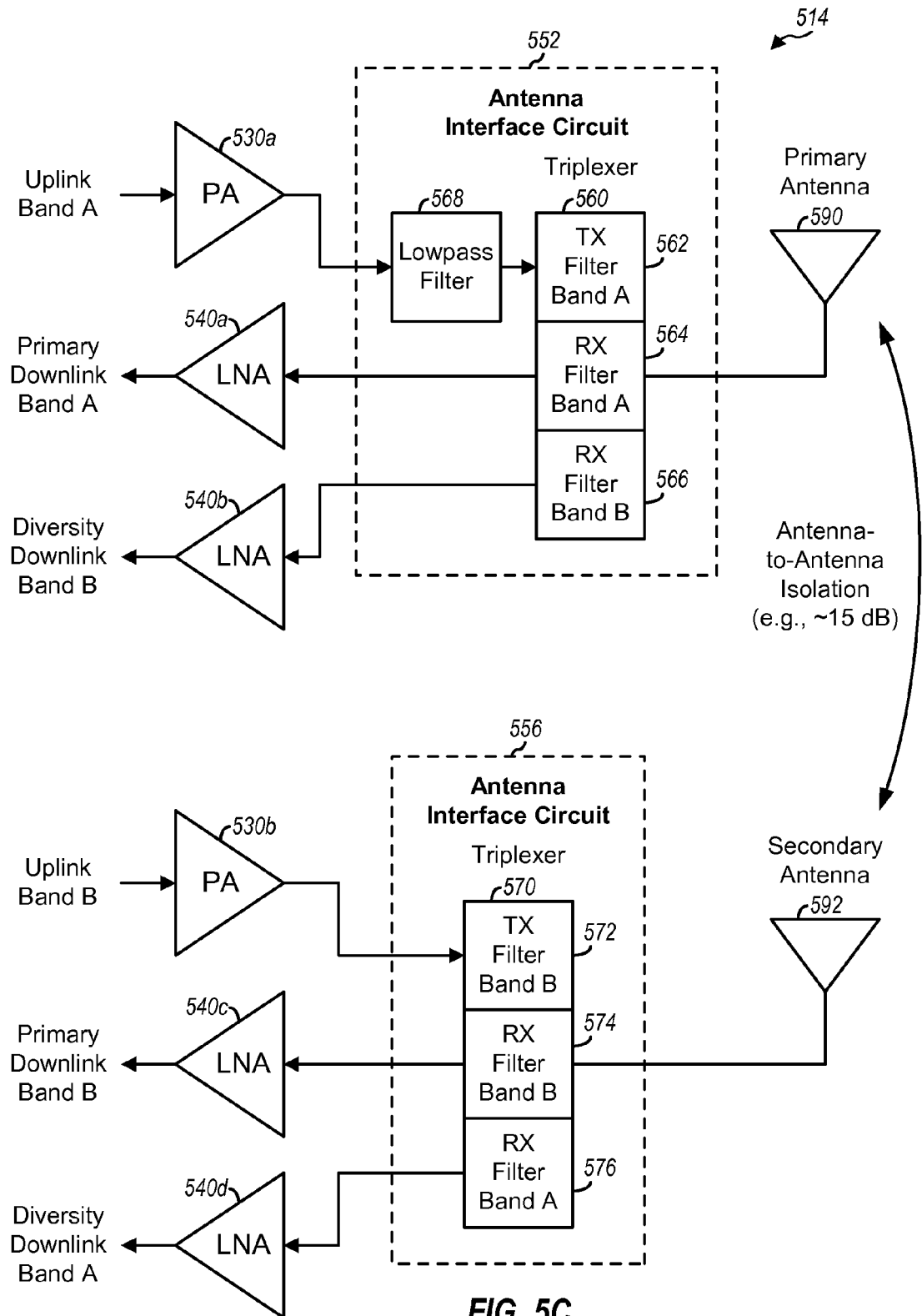


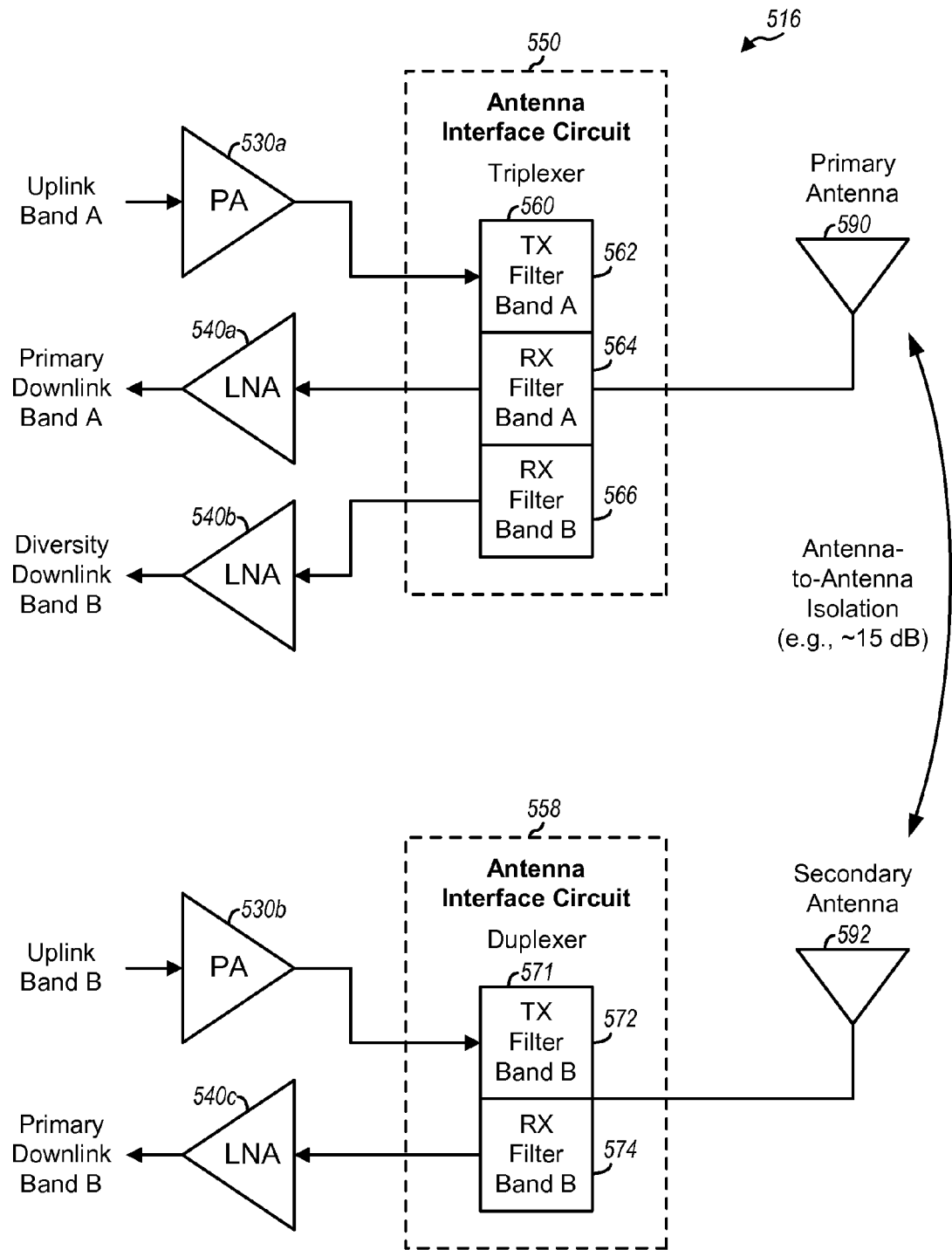
FIG. 4B











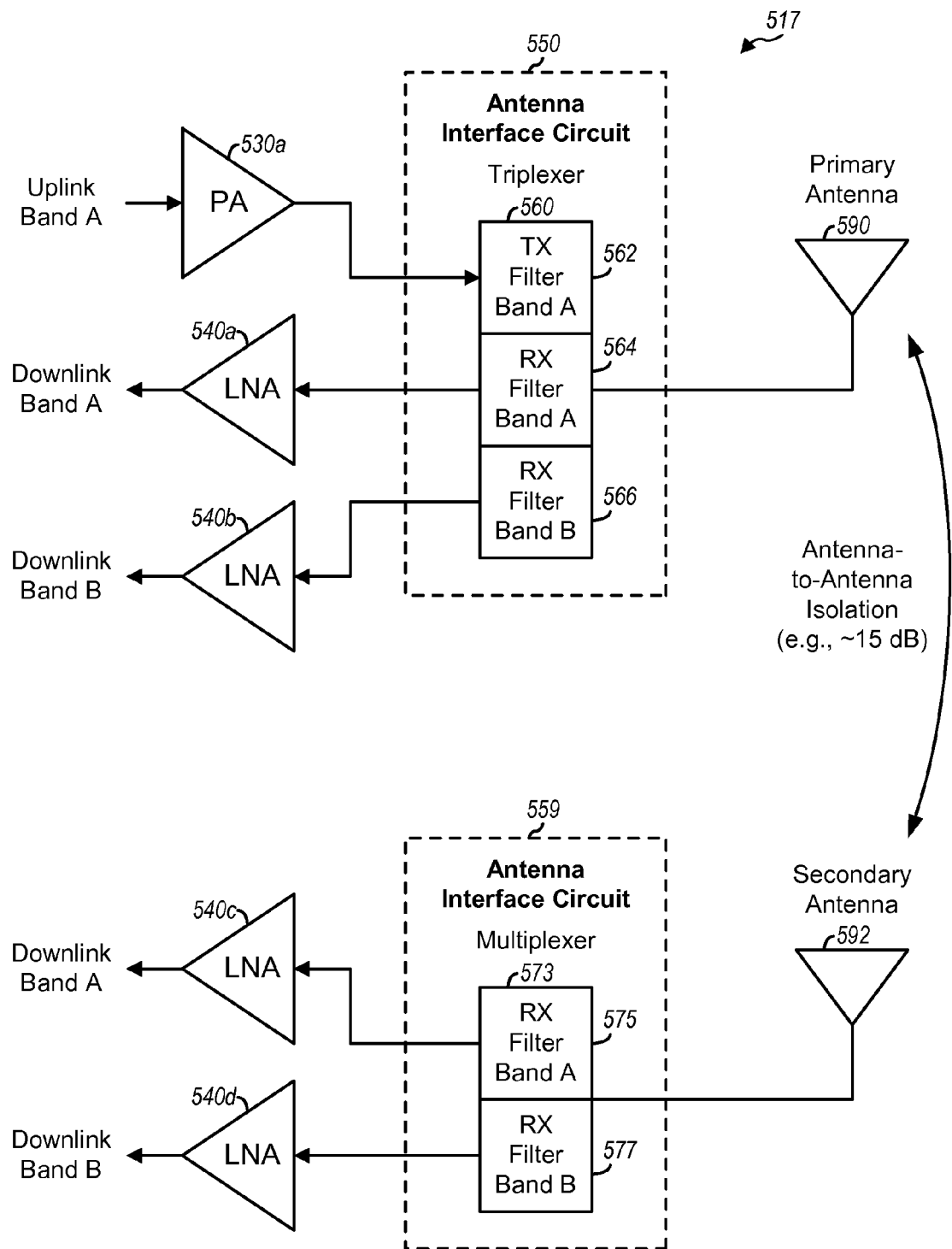


FIG. 5E

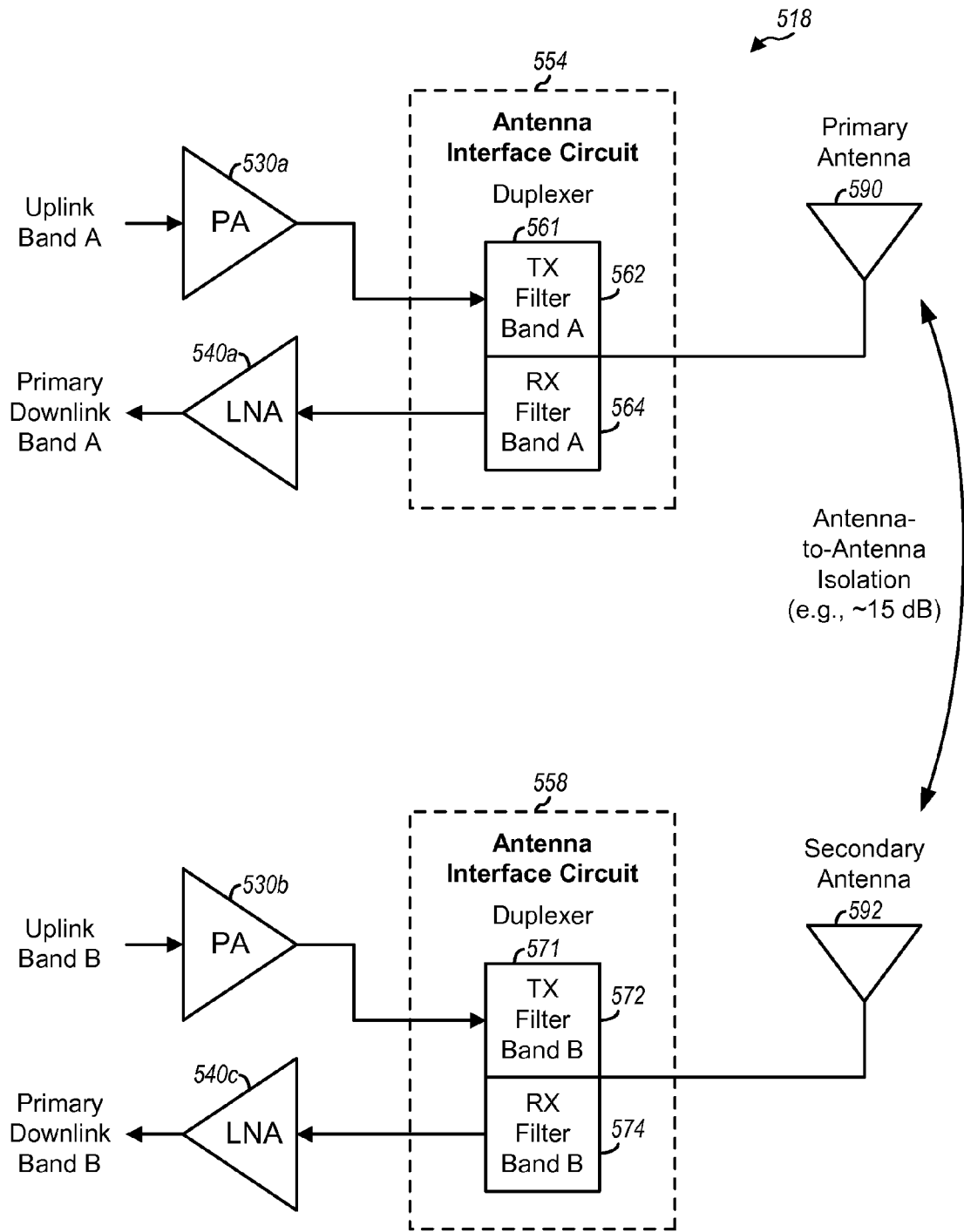
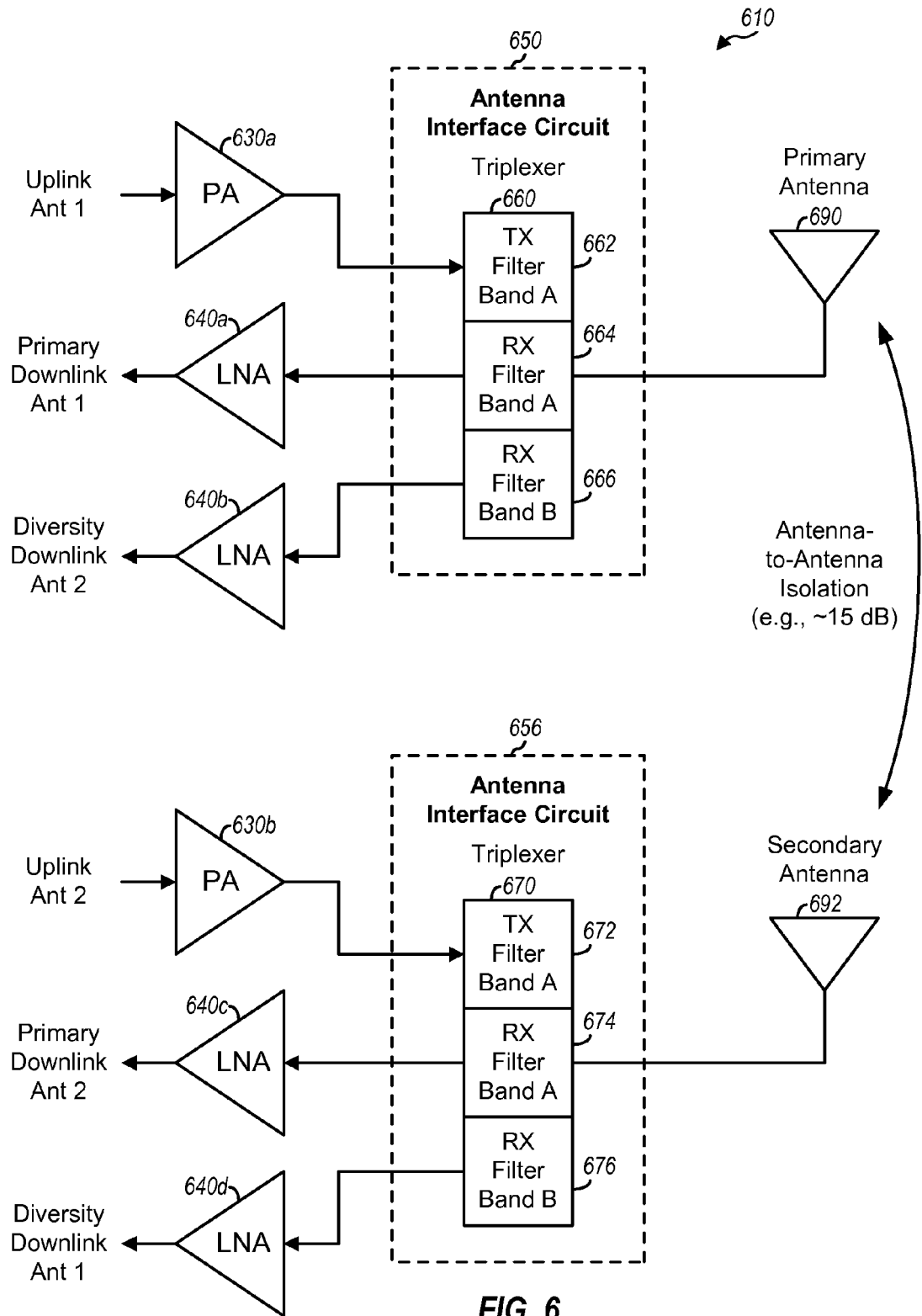
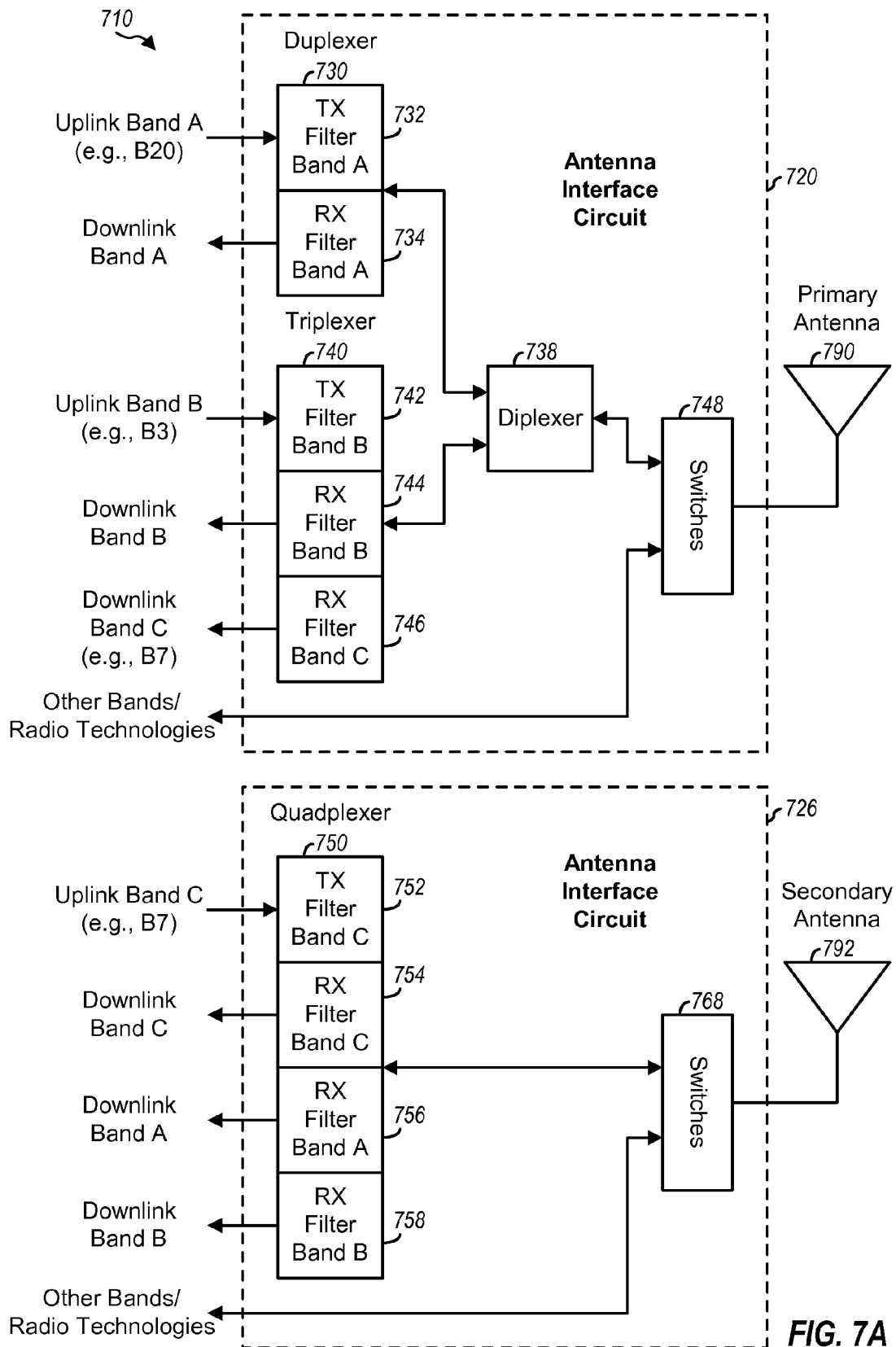


FIG. 5F





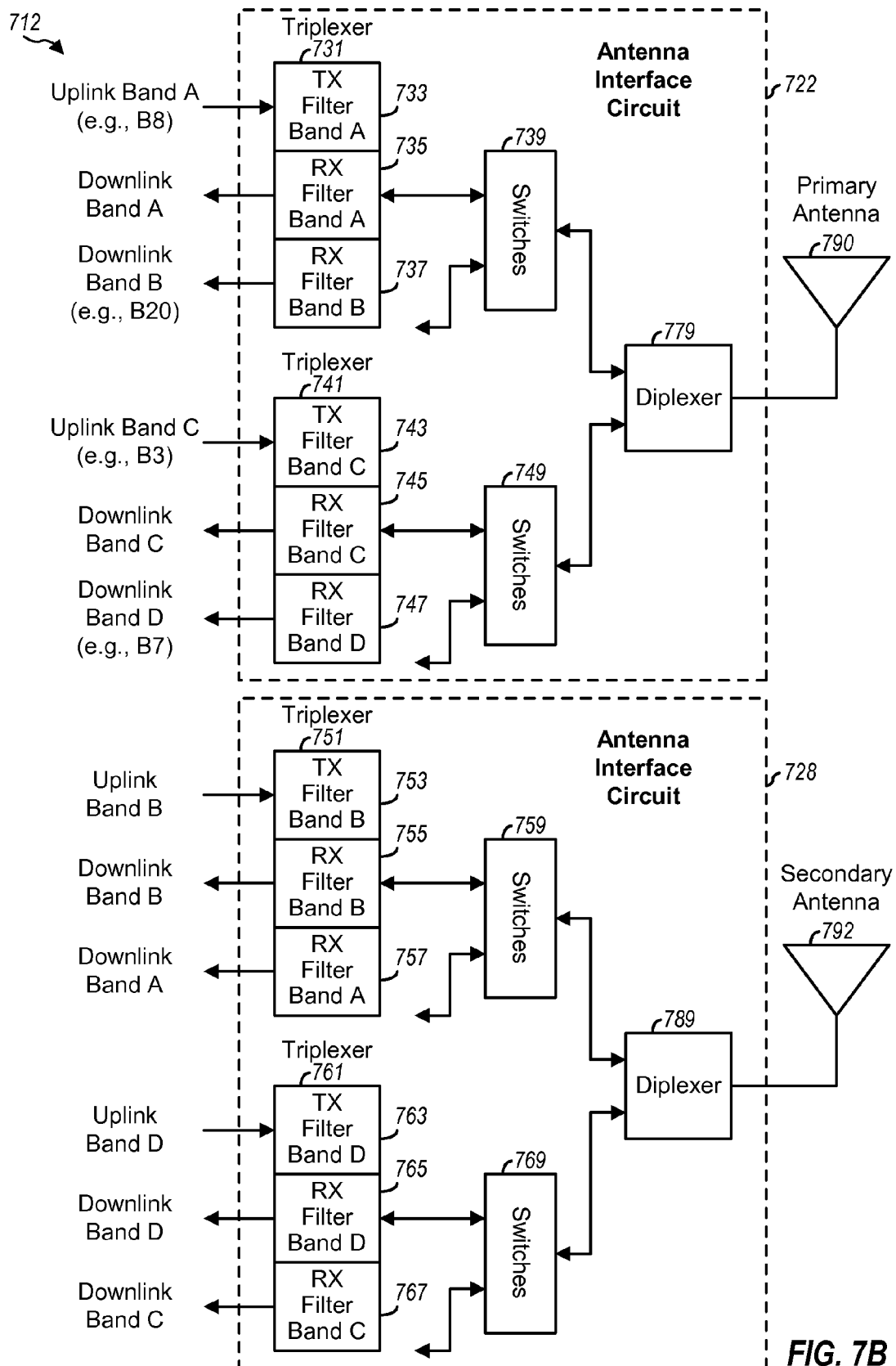


FIG. 7B



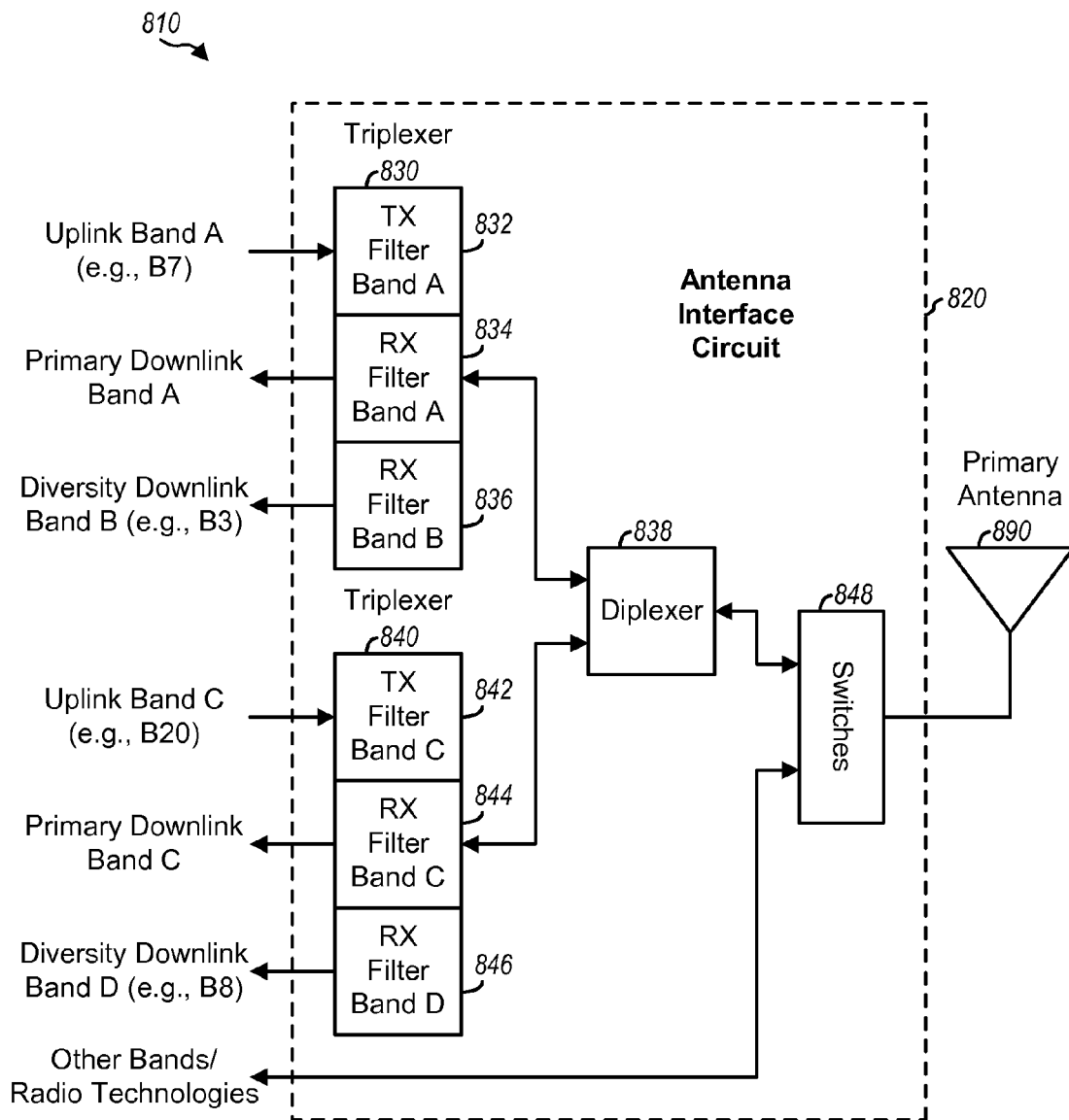


FIG. 8A

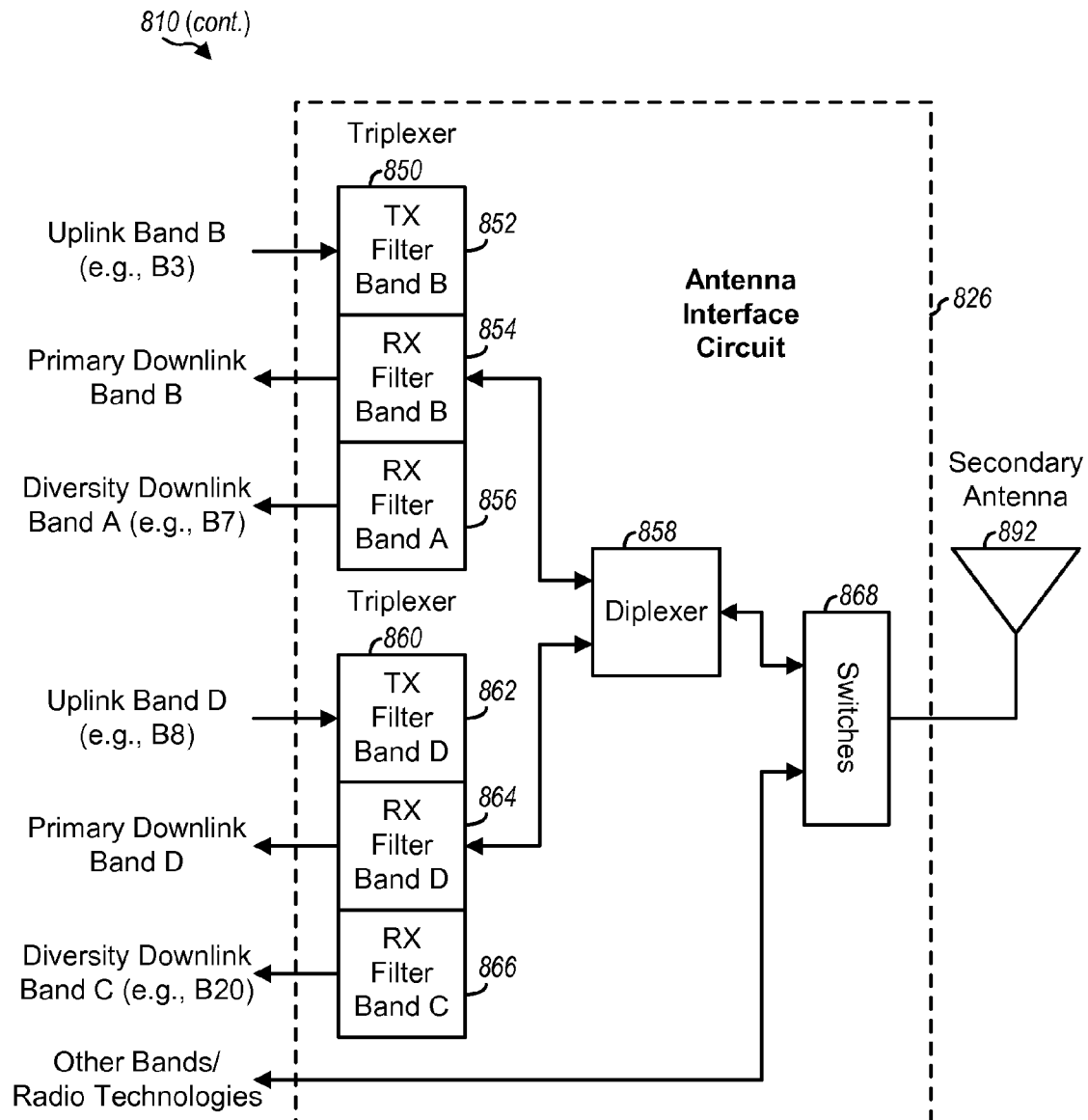
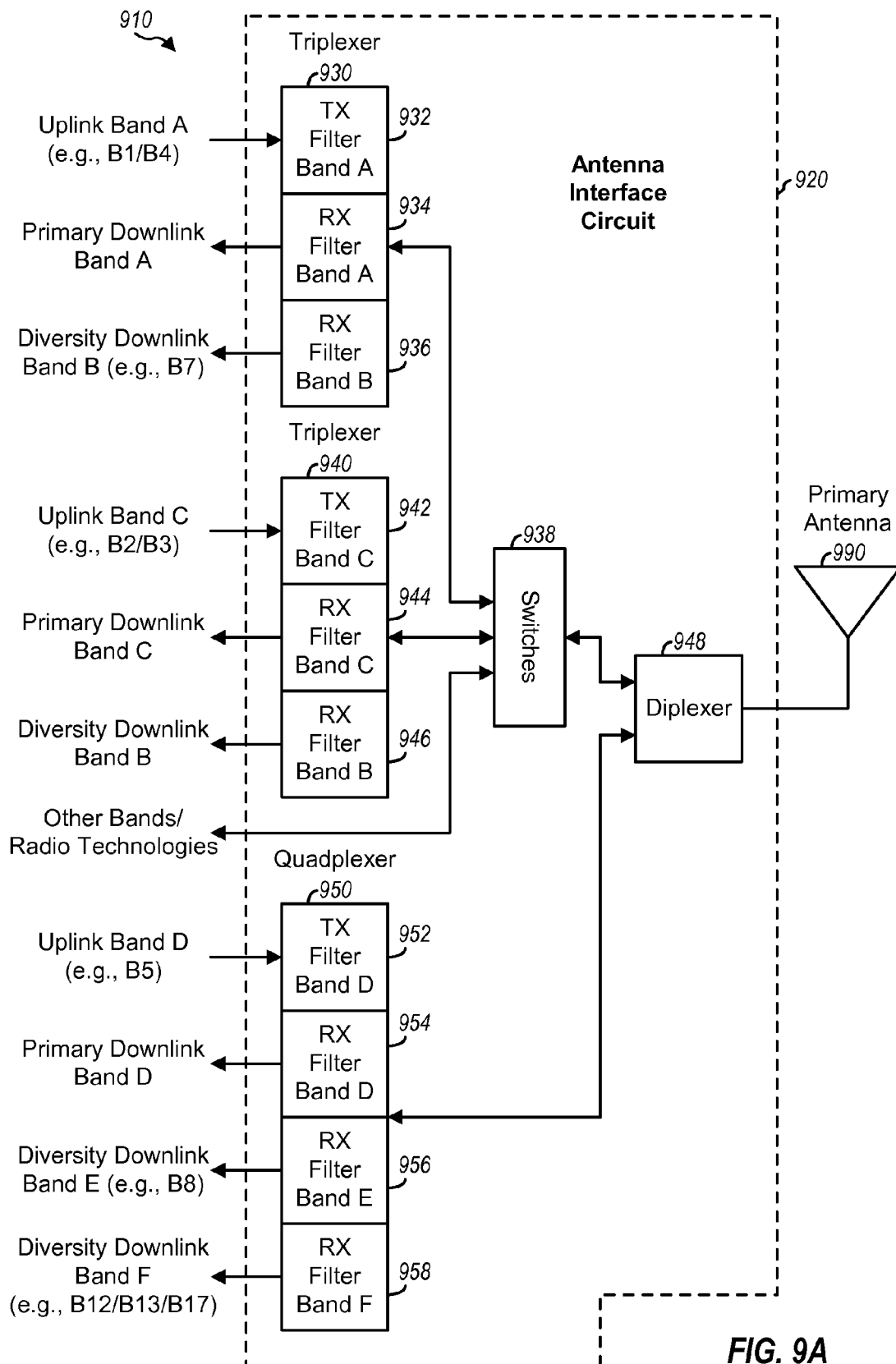
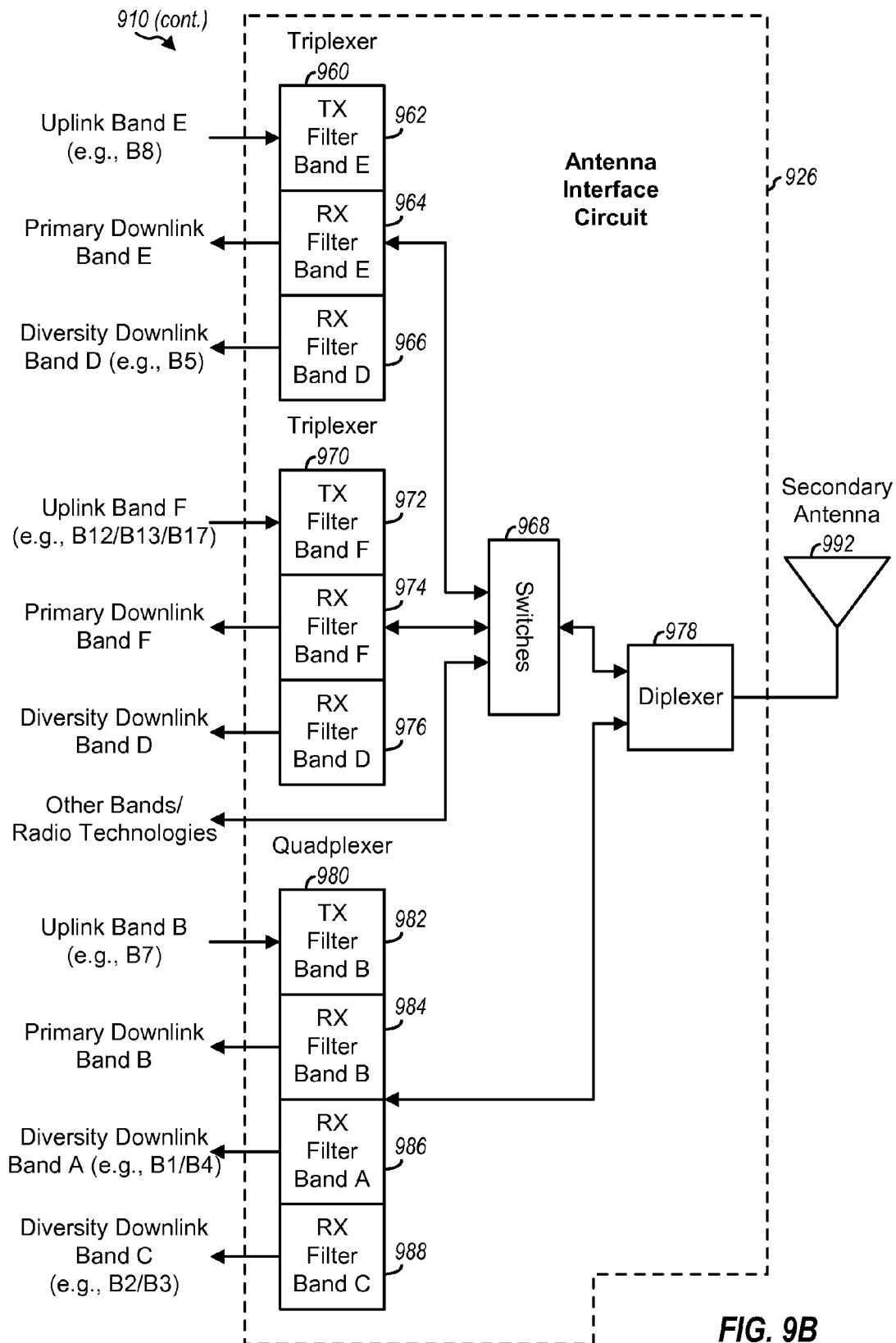


FIG. 8B





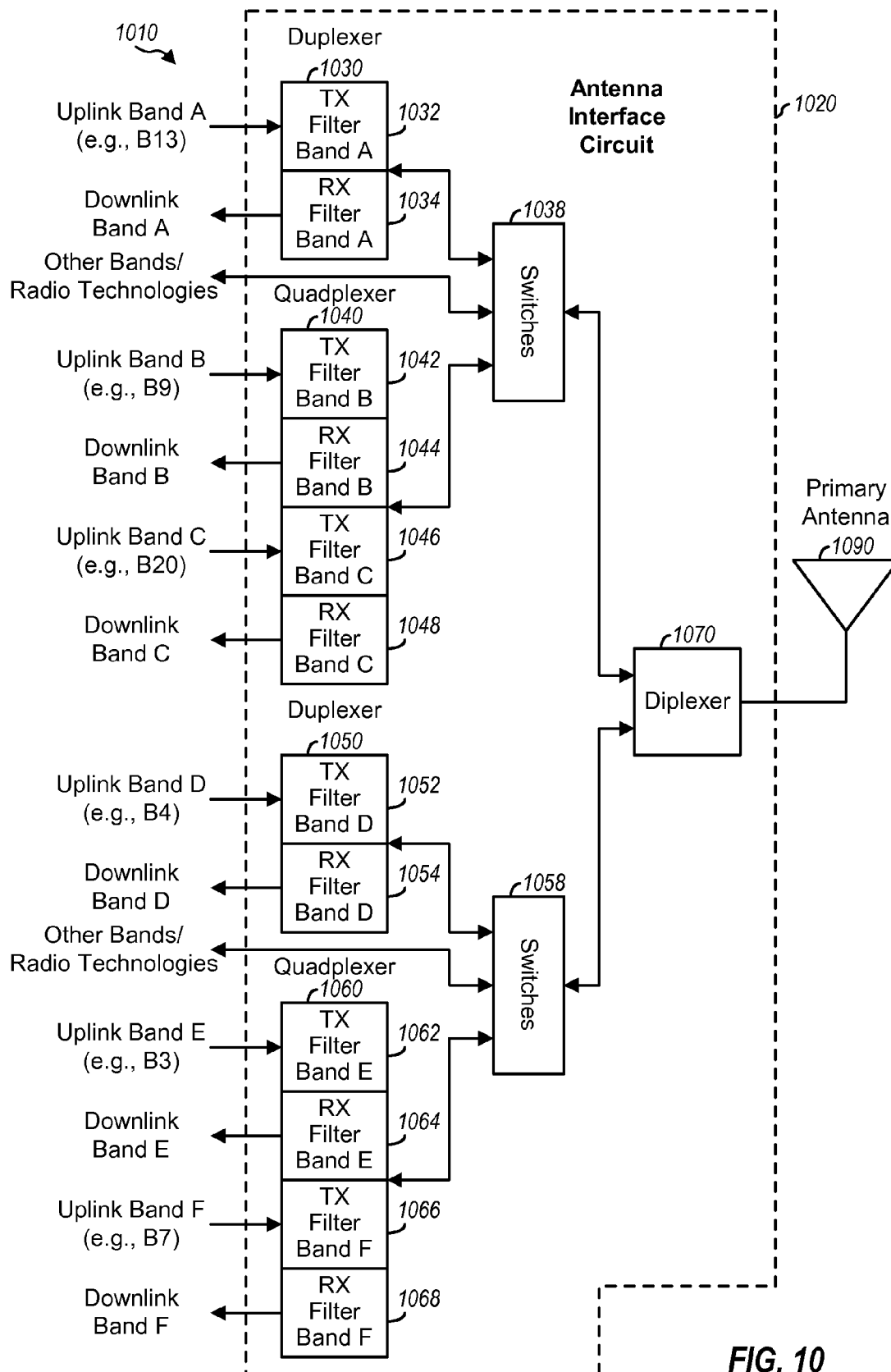
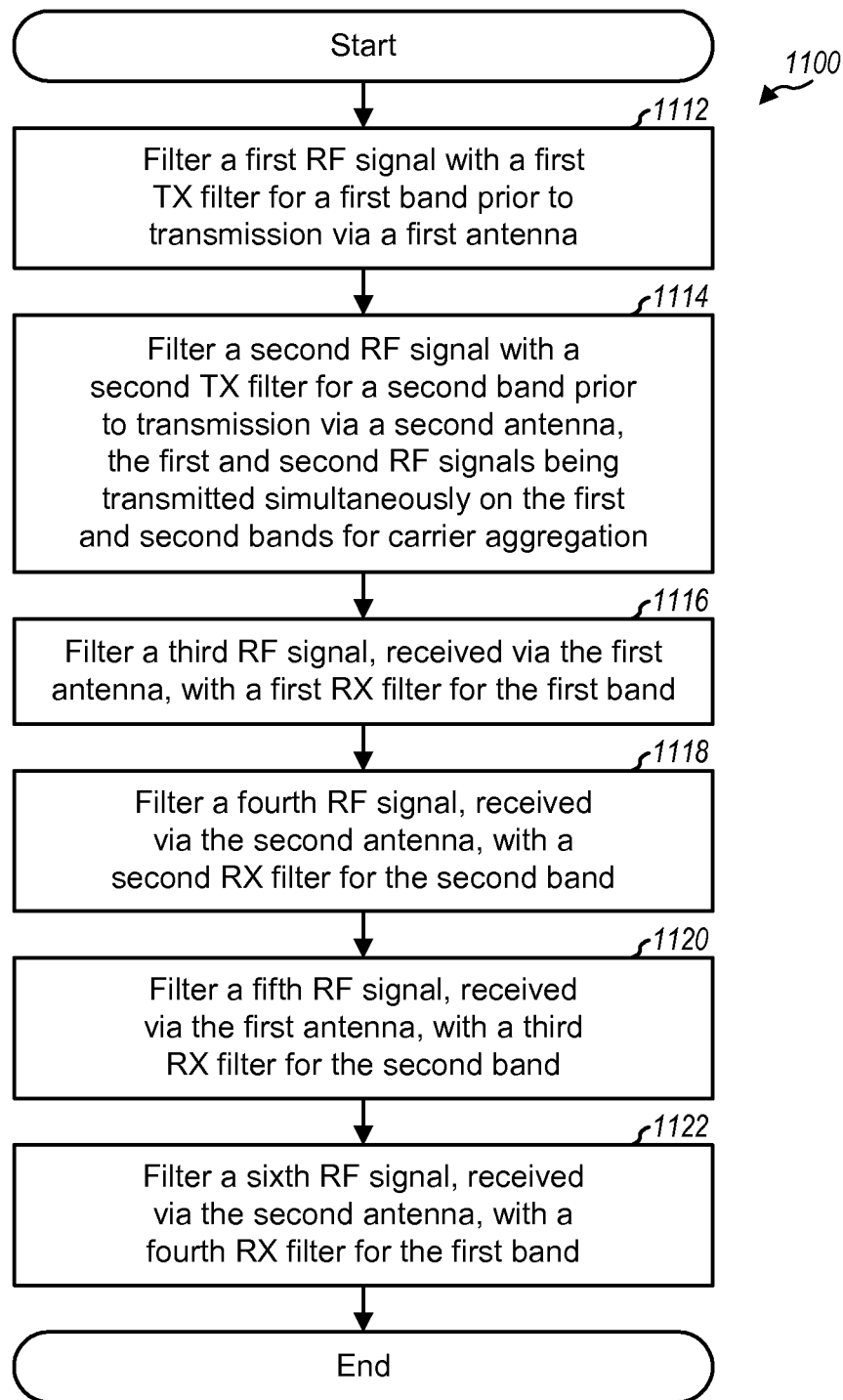


FIG. 10

**FIG. 11**

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# ANTENNA INTERFACE CIRCUITS FOR CARRIER AGGREGATION ON MULTIPLE ANTENNAS

CLAIM OF PRIORITY UNDER 35 U.S.C. §119

The present application for patent claims priority to Provisional U.S. Application Ser. No. 61/666,088, entitled "ANTENNA INTERFACE CIRCUITS FOR CARRIER AGGREGATION ON MULTIPLE ANTENNAS," filed Jun. 29, 2012, assigned to the assignee hereof, and expressly incorporated herein by reference.

## BACKGROUND

### I. Field

The present disclosure relates generally to electronics, and more specifically to antenna interface circuits and filters for wireless devices.

### II. Background

A wireless device (e.g., a cellular phone or a smartphone) in a wireless communication system may transmit and receive data for two-way communication. The wireless device may include a transmitter for data transmission and a receiver for data reception. For data transmission, the transmitter may modulate a radio frequency (RF) carrier signal with data to obtain a modulated RF signal, amplify the modulated RF signal to obtain an output RF signal having the proper output power level, and transmit the output RF signal via an antenna to a base station. For data reception, the receiver may obtain a received RF signal via the antenna and may amplify and process the received RF signal to recover data sent by the base station.

A wireless device may support carrier aggregation, which is simultaneous operation on multiple carriers. A carrier may refer to a range of frequencies used for communication and may be associated with certain characteristics. For example, a carrier may be associated with system information describing operation on the carrier. A carrier may also be referred to as a component carrier (CC), a frequency channel, a cell, etc. It is desirable to efficiently support carrier aggregation by the wireless device.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a wireless device communicating with a wireless system.

FIGS. 2A to 2D show four examples of carrier aggregation (CA).

FIG. 3 shows a block diagram of the wireless device in FIG. 1.

FIGS. 4A and 4B show two exemplary designs of an RF front-end unit supporting carrier aggregation on two bands via two antennas with full multiplexing.

FIGS. 5A to 5F show six exemplary designs of an RF front-end unit supporting carrier aggregation on two bands via two antennas with partial multiplexing.

FIG. 6 shows an exemplary design of an RF front-end unit supporting multiple-input multiple-output (MIMO) communication and carrier aggregation on one band via two antennas.

FIG. 7A shows an exemplary design of an RF front-end unit supporting carrier aggregation on three bands via two antennas with partial multiplexing.

FIG. 7B shows an exemplary design of an RF front-end unit supporting carrier aggregation on four bands via two antennas with partial multiplexing.

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FIGS. 8A and 8B show an exemplary design of an RF front-end unit supporting carrier aggregation on four bands via two antennas with partial multiplexing.

FIGS. 9A and 9B show an exemplary design of an RF front-end unit supporting carrier aggregation on six bands via two antennas with partial multiplexing.

FIG. 10 shows an exemplary design of an RF front-end unit supporting communicating on six bands.

FIG. 11 shows a process for supporting carrier aggregation with partial multiplexing.

## DETAILED DESCRIPTION

The detailed description set forth below is intended as a description of exemplary designs of the present disclosure and is not intended to represent the only designs in which the present disclosure can be practiced. The term "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any design described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other designs. The detailed description includes specific details for the purpose of providing a thorough understanding of the exemplary designs of the present disclosure. It will be apparent to those skilled in the art that the exemplary designs described herein may be practiced without these specific details. In some instances, well-known structures and devices are shown in block diagram form in order to avoid obscuring the novelty of the exemplary designs presented herein.

Antenna interface circuits and filters that can efficiently support carrier aggregation on multiple bands via multiple antennas are disclosed herein. These antenna interface circuits and filters may provide various advantages and may be used for various types of electronic devices such as wireless communication devices.

FIG. 1 shows a wireless device **110** capable of communicating with a wireless communication system **120**. Wireless system **120** may be a Long Term Evolution (LTE) system, a Code Division Multiple Access (CDMA) system, a Global System for Mobile Communications (GSM) system, a wireless local area network (WLAN) system, or some other wireless system. A CDMA system may implement Wideband CDMA (WCDMA), CDMA 1x, Time Division Synchronous CDMA (TD-SCDMA), or some other version of CDMA. For simplicity, FIG. 1 shows wireless system **120** including two base stations **130** and **132** and one system controller **140**. In general, a wireless system may include any number of base stations and any set of network entities.

Wireless device **110** may also be referred to as a user equipment (UE), a mobile station, a terminal, an access terminal, a subscriber unit, a station, etc. Wireless device **110** may be a cellular phone, a smartphone, a tablet, a wireless modem, a personal digital assistant (PDA), a handheld device, a laptop computer, a smartbook, a netbook, a cordless phone, a wireless local loop (WLL) station, a Bluetooth device, etc. Wireless device **110** may be capable of communicating with wireless system **120**. Wireless device **110** may also be capable of receiving signals from broadcast stations (e.g., a broadcast station **134**), signals from satellites (e.g., a satellite **150**) in one or more global navigation satellite systems (GNSS), etc. Wireless device **110** may support one or more radio technologies for wireless communication such as LTE, WCDMA, CDMA 1x, TD-SCDMA, GSM, 802.11, etc.

Wireless device **110** may support carrier aggregation, which is operation on multiple carriers. Carrier aggregation may also be referred to as multi-carrier operation. Wireless device **110** may be able to operate in low-band from 698 to 960 megahertz (MHz), mid-band from 1475 to 2170 MHz,

and/or high-band from 2300 to 2690 and 3400 to 3800 MHz. Low-band, mid-band, and high-band refer to three groups of bands (or band groups), with each band group including a number of frequency bands (or simply, “bands”). Each band may cover up to 200 MHz and may include one or more carriers. Each carrier may cover up to 20 MHz in LTE. LTE Release 11 supports 35 bands, which are referred to as LTE/UMTS bands and are listed in 3GPP TS 36.101. Wireless device 110 may be configured with up to 5 carriers in one or two bands in LTE Release 11.

In general, carrier aggregation (CA) may be categorized into two types—*intra-band CA* and *inter-band CA*. *Intra-band CA* refers to operation on multiple carriers within the same band. *Inter-band CA* refers to operation on multiple carriers in different bands.

FIG. 2A shows an example of contiguous *intra-band CA*. In the example shown in FIG. 2A, wireless device 110 is configured with four contiguous carriers in the same band in low-band. Wireless device 110 may send and/or receive transmissions on multiple contiguous carriers within the same band.

FIG. 2B shows an example of non-contiguous *intra-band CA*. In the example shown in FIG. 2B, wireless device 110 is configured with four non-contiguous carriers in the same band in low-band. The carriers may be separated by 5 MHz, 10 MHz, or some other amount. Wireless device 110 may send and/or receive transmissions on multiple non-contiguous carriers within the same band.

FIG. 2C shows an example of *inter-band CA* in the same band group. In the example shown in FIG. 2C, wireless device 110 is configured with four carriers in two bands in low-band. Wireless device 110 may send and/or receive transmissions on multiple carriers in different bands in the same band group.

FIG. 2D shows an example of *inter-band CA* in different band groups. In the example shown in FIG. 2D, wireless device 110 is configured with four carriers in two bands in different band groups, which include two carriers in one band in low-band and two additional carriers in another band in mid-band. Wireless device 110 may send and/or receive transmissions on multiple carriers in different bands in different band groups.

FIGS. 2A to 2D show four examples of carrier aggregation. Carrier aggregation may also be supported for other combinations of bands and band groups. For example, carrier aggregation may be supported for low-band and high-band, mid-band and high-band, high-band and high-band, etc.

*Inter-band CA* may be grouped into four classes/categories, which may include the following:

- Class A1—low-band and high-band combination without harmonic relation between bands,
- Class A2—low-band and high-band combination with harmonic relation between bands,
- Class A3—low-band and low-band combination or high-band and high-band combination without intermodulation (IM) problems (low-order IM), and
- Class A4—low-band and low-band combination or high-band and high-band combination with intermodulation problems (low-order IM).

Wireless device 110 may be designed to meet the requirements for all four classes/categories of *inter-band CA* listed above.

FIG. 3 shows a block diagram of an exemplary design of wireless device 110 in FIG. 1. In this exemplary design, wireless device 110 includes a data processor/controller 310, a transceiver 320 coupled to a primary antenna 390, and a transceiver 322 coupled to a secondary antenna 392. Transceiver 320 includes K transmitters 330<sub>pa</sub> to 330<sub>pk</sub>, L receivers

340<sub>pa</sub> to 340<sub>pl</sub>, and an antenna interface circuit 350 to support multiple bands, carrier aggregation, multiple radio technologies, etc. K and L may each be any integer value of one or greater. Transceiver 322 includes M transmitters 330<sub>sa</sub> to 330<sub>sm</sub>, N receivers 340<sub>sa</sub> to 340<sub>sn</sub>, and an antenna interface circuit 356 to support multiple bands, carrier aggregation, multiple radio technologies, receive diversity, multiple-input multiple-output (MIMO) transmission, etc. M and N may each be any integer value of one or greater.

In the exemplary design shown in FIG. 3, each transmitter 330 includes transmit circuits 332 and a power amplifier (PA) 334. For data transmission, data processor 310 processes (e.g., encodes and modulates) data to be transmitted and provides an analog output signal to a selected transmitter. The description below assumes that transmitter 330<sub>pa</sub> is the selected transmitter. Within transmitter 330<sub>pa</sub>, transmit circuits 332<sub>pa</sub> amplify, filter, and upconvert the analog output signal from baseband to RF and provide a modulated RF signal. Transmit circuits 332<sub>pa</sub> may include amplifiers, filters, mixers, matching circuits, an oscillator, a local oscillator (LO) generator, a phase-locked loop (PLL), etc. A PA 334<sub>pa</sub> receives and amplifies the modulated RF signal and provides an output RF signal having the proper output power level. The output RF signal is routed through antenna interface circuit 350 and transmitted via antenna 390. Antenna interface circuit 350 may include one or more filters, duplexers, triplexers, quadplexers, switches, matching circuits, directional couplers, etc. Each remaining transmitter 330 in transceivers 320 and 322 may operate in similar manner as transmitter 330<sub>pa</sub>.

In the exemplary design shown in FIG. 3, each receiver 340 includes a low noise amplifier (LNA) 342 and receive circuits 344. For data reception, antenna 390 receives signals from base stations and/or other transmitter stations and provides a received RF signal, which is routed through antenna interface circuit 350 and provided to a selected receiver. The description below assumes that receiver 340<sub>pa</sub> is the selected receiver. Within receiver 340<sub>pa</sub>, LNA 342<sub>pa</sub> amplifies the received RF signal and provides an amplified RF signal. Receive circuits 344<sub>pa</sub> downconvert the amplified RF signal from RF to baseband, amplify and filter the downconverted signal, and provide an analog input signal to data processor 310. Receive circuits 344<sub>pa</sub> may include mixers, filters, amplifiers, matching circuits, an oscillator, an LO generator, a PLL, etc. Each remaining receiver 340 in transceivers 320 and 322 may operate in similar manner as receiver 340<sub>pa</sub>.

FIG. 3 shows an exemplary design of transmitters 330 and receivers 340. A transmitter and a receiver may also include other circuits not shown in FIG. 3, such as filters, matching circuits, etc. All or a portion of transceivers 320 and 322 may be implemented on one or more analog integrated circuits (ICs), RF ICs (RFICs), mixed-signal ICs, etc. For example, transmit circuits 332, LNAs 342, and receive circuits 344 may be implemented on one module, which may be an RFIC, etc. Antenna interface circuits 350 and 356 and PAs 334 may be implemented on another module, which may be a hybrid module, etc. The circuits in transceivers 320 and 322 may also be implemented in other manners.

Data processor/controller 310 may perform various functions for wireless device 110. For example, data processor 310 may perform processing for data being transmitted via transmitters 330 and data being received via receivers 340. Controller 310 may control the operation of transmit circuits 332, PAs 334, LNAs 342, receive circuits 344, antenna interface circuits 350 and 356, or a combination thereof. A memory 312 may store program codes and data for data processor/controller 310. Data processor/controller 310 may



be implemented on one or more application specific integrated circuits (ASICs) and/or other ICs.

Antenna interface circuits **350** and **356** may be implemented in various manners to support carrier aggregation. Some exemplary designs of antenna interface circuits **350** and **356** are described below. In general, an antenna interface circuit may include any number of duplexers, diplexers, triplexers, quadplexers, switches, etc. A duplexer typically includes a transmit (TX) filter for data transmission and a receive (RX) filter for data reception. The TX filter and the RX filter are typically designed for a particular band. A diplexer typically includes a lowpass filter and a highpass filter, which may be used to separate signals in two band groups.

FIG. 4A shows an exemplary design of an RF front-end unit **410** comprising antenna interface circuits **450** and **456** supporting carrier aggregation on two bands A and B. Antenna interface circuits **450** and **456** may be used for antenna interface circuits **350** and **356**, respectively, in FIG. 3. Antenna interface circuit **450** supports data transmission on the uplink on bands A and B and data reception on the downlink on bands A and B via a primary antenna **490**. Antenna interface circuit **456** supports data reception on the downlink on bands A and B via a secondary antenna **492** for receive diversity.

Antenna interface circuit **450** includes a duplexer **460a** for band A, a duplexer **460b** for band B, and a diplexer **466**. Duplexer **460a** includes a TX filter **462a** for band A coupled to a PA **430a** and an RX filter **464a** for band A coupled to an LNA **440a**. The output of TX filter **462a** and the input of RX filter **464a** are coupled to an output of duplexer **460a**. Duplexer **460b** includes a TX filter **462b** for band B coupled to a PA **430b** and an RX filter **464b** for band B coupled to an LNA **440b**. The output of TX filter **462b** and the input of RX filter **464b** are coupled to an output of duplexer **460b**. Diplexer **466** includes a first input coupled to the output of duplexer **460a**, a second input coupled to the output of duplexer **460b**, and an output coupled to antenna **490**. Diplexer **466** includes a lowpass filter and a highpass filter, with one filter being coupled between the first input and the output of diplexer **466**, and the other filter being coupled between the second input and the output of diplexer **466**. For example, band A may be in low-band, and band B may be in high-band. Duplexer **460a** may then be coupled to the low-pass filter within diplexer **466**, and duplexer **460b** may be coupled to the highpass filter within diplexer **466**.

Antenna interface circuit **456** includes an RX filter **474a** for band A, an RX filter **474b** for band B, and a diplexer **476**. RX filter **474a** is coupled between an LNA **440c** and diplexer **476**. RX filter **474b** is coupled between an LNA **440d** and diplexer **476**. Diplexer **476** has its output coupled to antenna **492**, which is a secondary/diversity antenna.

FIG. 4B shows an exemplary design of an RF front-end unit **412** comprising antenna interface circuits **452** and **456** supporting carrier aggregation on two bands A and B. Antenna interface circuit **452** may be used for antenna interface circuit **350** in FIG. 3. Antenna interface circuit **452** includes a quadplexer **461** for bands A and B. Quadplexer **461** includes TX filter **462a** and RX filter **464a** for band A and TX filter **462b** and RX filter **464b** for band B. The outputs of TX filters **462a** and **462b** and the inputs of RX filters **464a** and **464b** are coupled to an output of quadplexer **461**, which is coupled to antenna **490**.

The exemplary design in FIG. 4A uses (i) two duplexers **460a** and **460b** and one diplexer **466** for primary antenna **490** and (ii) two RX filters **474a** and **474b** and one diplexer **476** for secondary/diversity antenna **492**. For class A2 and class A4

inter-band CA, a harmonic rejection filter may be coupled between each duplexer **460** and diplexer **466**. The exemplary design in FIG. 4B uses (i) quadplexer **461** that combines the two duplexers **460a** and **460b** together for primary antenna **490** and (ii) two RX filters **474a** and **474b** and one diplexer **476** for secondary/diversity antenna **492**. The exemplary designs in FIGS. 4A and 4B may have a larger circuit size and additional components, which may increase the cost of a wireless device. The exemplary designs in FIGS. 4A and 4B may also have higher insertion loss due to additional components and matching issues, which may adversely impact the performance of a wireless device.

The exemplary designs in FIGS. 4A and 4B support carrier aggregation on two bands with “full” multiplexing of two bands A and B on one antenna. In particular, data transmission and reception on both bands A and B are supported via primary antenna **490** using either (i) two duplexers **460a** and **460b** and diplexer **466** in FIG. 4A or (ii) quadplexer **461** in FIG. 4B.

Carrier aggregation with full multiplexing may have various disadvantages. First, combining two duplexers into a quadplexer (e.g., as shown in FIG. 4B) or using two duplexers and a diplexer (e.g., as shown in FIG. 4A) may be harder to implement, especially when the frequency gap between two bands A and B is small. Second, insertion loss for a quadplexer (e.g., as shown in FIG. 4B) or combined duplexers with diplexer (e.g., as shown in FIG. 4A) may be relatively high, which may degrade the performance of a transceiver. Third, sending data transmissions simultaneously on two bands via the same antenna may require extra design efforts in order to achieve sufficiently low harmonic and intermodulation distortion (IMD) products. Fourth, the exemplary designs in FIGS. 4A and 4B may result in larger circuit area, higher component count, and/or higher cost.

In an aspect of the present disclosure, carrier aggregation may be supported with “partial” multiplexing of transmissions on multiple bands via multiple antennas. Partial multiplexing refers to transmission on only a subset of the multiple bands via each antenna. For example, carrier aggregation on two bands A and B may be supported by transmitting on band A via a primary antenna and transmitting on band B via a secondary antenna. Partial multiplexing may provide benefits from antenna-to-antenna isolation, which may reduce power levels of harmonics and IMD products generated due to non-linearity of circuits when data transmission and reception occur simultaneously on multiple bands. Partial multiplexing may also result in simpler circuits, which may reduce the size and cost of a wireless device.

FIG. 5A shows an exemplary design of an RF front-end unit **510** comprising antenna interface circuits **550** and **556** supporting carrier aggregation on two bands A and B via two antennas with partial multiplexing and diversity reception for both bands. Antenna interface circuits **550** and **556** may be used for antenna interface circuits **350** and **356**, respectively, in FIG. 3. Antenna interface circuit **550** supports data transmission on the uplink on band A and data reception on the downlink on bands A and B via a primary antenna **590**. Antenna interface circuit **556** supports data transmission on the uplink on band B and data reception on the downlink on bands A and B via a secondary antenna **592**.

In the exemplary design shown in FIG. 5A, antenna interface circuit **550** includes a triplexer **560** for bands A and B. Triplexer **560** includes a TX filter **562** for band A coupled to a PA **530a**, an RX filter **564** for band A coupled to an LNA **540a**, and an RX filter **566** for band B coupled to an LNA

**540b**. The output of TX filter **562** and the inputs of RX filters **564** and **566** are coupled to an output of triplexer **560**, which is coupled to antenna **590**.

In general, a “triplexer” is a circuit module/block comprising at least three filters, e.g., one TX filter and two RX filters. A triplexer may also include more than three filters, and all or a subset of the filters may be used. For example, a triplexer may include four filters, but only three filters may be used and may be coupled to the inputs and output of the triplexer. A “multiplexer” is a circuit module/block comprising at least two filters. A multiplexer may be a diplexer, a triplexer, a quadplexer, etc.

In the exemplary design shown in FIG. 5A, antenna interface circuit **556** includes a triplexer **570** for bands A and B. Triplexer **570** includes a TX filter **572** for band B coupled to a PA **530b**, an RX filter **574** for band B coupled to an LNA **540c**, and an RX filter **576** for band A coupled to an LNA **540d**. The output of TX filter **572** and the inputs of RX filters **574** and **576** are coupled to an output of triplexer **570**, which is coupled to antenna **592**.

TX filters **562** and **572** and RX filters **564**, **566**, **574** and **576** may be implemented in various manners. A TX filter or an RX filter may be implemented with a surface acoustic wave (SAW) filter, a bulk acoustic wave (BAW) filter, a thin film bulk acoustic resonator (FBAR) filter, a micro-electro-mechanical system (MEMS) filter, a ceramic filter, etc.

In the exemplary design shown in FIG. 5A, data transmission and reception for band A as well as diversity data reception for band B are supported via antenna interface circuit **550** and primary antenna **590**. Data transmission and reception for band B as well as diversity data reception for band A are supported via antenna interface circuit **556** and secondary antenna **592**. Antenna-to-antenna isolation between primary antenna **590** and secondary antenna **592** may be exploited in order to reduce power levels of harmonics and IMD products, which may improve performance.

FIG. 5B shows an exemplary design of an RF front-end unit **512** comprising antenna interface circuits **550** and **556** supporting carrier aggregation on two bands A and B. In the exemplary design shown in FIG. 5B, data transmission and primary data reception for band A as well as primary data reception for band B are supported via antenna interface circuit **550** and primary antenna **590**. Data transmission and diversity data reception for band B as well as diversity data reception for band A are supported via antenna interface circuit **556** and secondary antenna **592**.

FIG. 5C shows an exemplary design of an RF front-end unit **514** comprising antenna interface circuits **552** and **556** supporting carrier aggregation on two bands A and B. Antenna interface circuits **552** and **556** may be used for antenna interface circuits **350** and **356**, respectively, in FIG. 3. Antenna interface circuit **552** supports data transmission on the uplink on band A and data reception on the downlink on bands A and B via primary antenna **590**. Antenna interface circuit **556** supports data transmission on the uplink on band B and data reception on the downlink on bands A and B via secondary antenna **592**.

In the exemplary design shown in FIG. 5C, antenna interface circuit **552** includes a lowpass filter **568** and triplexer **560**. Lowpass filter **568** has its input coupled to the output of PA **530a** and its output coupled to the input of TX filter **562** within triplexer **560**. Lowpass filter **568** filters an amplified RF signal from PA **530a** to pass signal components within band A and attenuate high-frequency signal components higher than band A.

The amplified RF signal from PA **530a** may be transmitted in band A and may have a harmonic that falls within a receive

frequency range of band B. For example, the amplified RF signal may be transmitted in Band 17 and may have a third harmonic that falls within the receive frequency range of Band 4. By locating TX for band A on primary antenna **590** and primary RX for band B on secondary antenna **592**, isolation between primary antenna **590** and secondary antenna **592** can be exploited to provide attenuation (e.g., of approximately 15 dB) of a harmonic of the amplified RF signal falling on band B. Lowpass filter **568** can filter the amplified RF signal and provide additional attenuation of the harmonic of the amplified RF signal. Lowpass filter **568** can thus provide rejection of the harmonic of the amplified RF signal on band A, which may be beneficial for both primary RX on band B via secondary antenna **592** and diversity RX on band B via primary antenna **590**.

Although not shown in FIG. 5C, a lowpass filter may be coupled between PA **530b** and TX filter **572** and may be used to attenuate out-of-band signal components (e.g., harmonics) of an amplified RF signal from PA **530b**.

FIG. 5D shows an exemplary design of an RF front-end unit **516** comprising antenna interface circuits **550** and **558** supporting carrier aggregation on two bands A and B via two antennas with diversity reception for only one band. Antenna interface circuits **550** and **558** may be used for antenna interface circuits **350** and **356**, respectively, in FIG. 3. Antenna interface circuit **550** supports data transmission on the uplink on band A and data reception on the downlink on bands A and B via primary antenna **590**. Antenna interface circuit **558** supports data transmission on the uplink and data reception on the downlink on band B via secondary antenna **592**. Antenna interface circuit **558** includes a duplexer **571** for band B. Duplexer **571** includes TX filter **572** for band B coupled to PA **530b** and RX filter **574** for band B coupled to LNA **540c**. The output of TX filter **572** and the input of RX filter **574** are coupled to an output of duplexer **571**, which is coupled to antenna **592**.

FIG. 5E shows an exemplary design of an RF front-end unit **517** comprising antenna interface circuits **550** and **559** supporting carrier aggregation on two bands A and B via two antennas with diversity reception for two bands. Antenna interface circuits **550** and **559** may be used for antenna interface circuits **350** and **356**, respectively, in FIG. 3. Antenna interface circuit **550** supports data transmission on the uplink on band A and data reception on the downlink on bands A and B via primary antenna **590**. Antenna interface circuit **559** supports data reception on the downlink on bands A and B via secondary antenna **592**. Antenna interface circuit **559** includes a multiplexer **573** for bands A and B. Multiplexer **573** includes an RX filter **575** for band A coupled to LNA **540c** and an RX filter **577** for band B coupled to an LNA **540d**. The outputs of RX filters **575** and **577** are coupled to an output of multiplexer **573**, which is coupled to antenna **592**.

FIG. 5F shows an exemplary design of an RF front-end unit **518** comprising antenna interface circuits **554** and **558** supporting carrier aggregation on two bands A and B via two antennas without diversity reception. Antenna interface circuits **554** and **558** may be used for antenna interface circuits **350** and **356**, respectively, in FIG. 3. Antenna interface circuit **554** supports data transmission on the uplink and data reception on the downlink on band A via primary antenna **590**. Antenna interface circuit **554** includes a duplexer **561** for band A. Duplexer **561** includes TX filter **562** for band A coupled to PA **530a** and RX filter **564** for band A coupled to LNA **540a**. The output of TX filter **562** and the input of RX filter **564** are coupled to an output of duplexer **561**, which is coupled to antenna **590**. Antenna interface circuit **558** sup-

ports data transmission on the uplink and data reception on the downlink on band B via secondary antenna 592 and is described above for FIG. 5D.

The exemplary designs shown in FIGS. 5A to 5F may be used to support various combinations of bands. Table 1 lists three exemplary combinations of bands that may be supported by the exemplary designs shown in FIGS. 5A to 5F. The bands in Table 1 are defined for LTE/UMTS and may be referred to as LTE bands. The frequencies in Table 1 are in units of MHz.

TABLE 1

	Band A		Band B	
	Uplink Frequency	Downlink Frequency	Uplink Frequency	Downlink Frequency
Example 1	Band 1 TX 1920 to 1980	Band 1 RX 2110 to 2170	Band 21 TX 1447.9 to 1462.9	Band 21 RX 1495.9 to 1510.9
Example 2	Band 5 TX 824 to 849	Band 5 RX 869 to 894	Band 12 TX 699 to 716	Band 12 RX 726 to 746
Example 3	Band 4 TX 1710 to 1755	Band 4 RX 2110 to 2155	Band 17 TX 704 to 716	Band 17 RX 734 to 736

In example 1 in Table 1, carrier aggregation is supported for Band 1 in high-band and Band 21 in mid-band. In example 2, carrier aggregation is supported for Band 5 in low-band and Band 12 in low-band. In example 3, carrier aggregation is supported for Band 4 in high-band and Band 17 in low-band. Band 17 has a TX/uplink frequency range of 704 to 716 MHz. The third harmonic of the uplink frequency range for Band 17 falls between 2112 and 2148 MHz, which overlaps the RX/downlink frequency range of 2110 to 2155 for Band 4. Data transmission on the uplink on Band 17 may interfere with data reception on the downlink on Band 4. The level/degree that Band 17 interferes with Band 4 may be dependent on various factors such as harmonic rejection in a low-band duplexer, harmonic rejection in a diplexer, and harmonic attenuation due to antenna-to-antenna isolation between the primary and secondary antennas. For example, the second harmonic of a transmit signal on Band 17 may mix with a received signal on Band 17 and may cause interference to a received signal on Band 4.

Partial multiplexing may provide various advantages for the band combinations in examples 1 to 3. First, antenna separation may result in minimal band matching. Second, lower insertion loss may be obtained, and it may be easier to match impedance and/or power for a triplexer (e.g., in FIG. 5A) than two duplexers (e.g., in FIG. 4A). Third, better isolation may be achieved between bands. Fourth, no additional RX filters may be required for receive diversity. Fifth, better immunity to harmonics and IMD products may be achieved between PAs. Sixth, no additional transmit antennas may be required, because the primary and secondary antennas typically already exist on many wireless devices.

FIGS. 5A to 5F show exemplary designs of RF front-end units supporting carrier aggregation on two bands A and B via two antennas with partial multiplexing. In general, partial multiplexing may be used to support carrier aggregation on any number of bands via any number of antennas. To support carrier aggregation with partial multiplexing on K bands via N antennas, where  $K > 1$  and  $N > 1$ , each antenna may support data transmission on a different subset of the K bands. In one exemplary design, the N antennas may support data transmission on the same number of bands. For example, each antenna may support data transmission on only one band, or on two bands, etc. In another exemplary design, the N antennas may

support data transmission on different numbers of bands. For example, one antenna may support data transmission on one band, another antenna may support data transmission on two bands, etc. For both exemplary designs, each antenna may also support data reception on any number of bands. The N antennas may support data reception on the same number of bands or on different numbers of bands. For example, each antenna may support data reception on all bands, or on one band, or on two bands, or on either one or two bands, etc.

FIG. 6 shows an exemplary design of an RF front-end unit 610 comprising antenna interface circuits 650 and 656 supporting MIMO communication and inter-band carrier aggregation on one band A and intra-band carrier aggregation on two bands A and B via two antennas. RF front-end unit 610 also supports inter-band carrier aggregation when band A supports both uplink and downlink whereas band B supports only downlink. Antenna interface circuits 650 and 656 may be used for antenna interface circuits 350 and 356, respectively, in FIG. 3. Antenna interface circuit 650 supports data transmission on the uplink and data reception on the downlink for a first antenna via a primary antenna 690. Antenna interface circuit 656 supports data transmission on the uplink and data reception on the downlink for a second antenna via a secondary antenna 692.

In the exemplary design shown in FIG. 6, antenna interface circuit 650 includes a triplexer 660 for bands A and B. Triplexer 660 includes a TX filter 662 coupled to a PA 630a, an RX filter 664 coupled to an LNA 640a, and an RX filter 666 coupled to an LNA 640b. The output of TX filter 662 and the inputs of RX filters 664 and 666 are coupled to an output of triplexer 660, which is coupled to antenna 690.

In the exemplary design shown in FIG. 6, antenna interface circuit 656 includes a triplexer 670 for bands A and B. Triplexer 670 includes a TX filter 672 coupled to a PA 630b, an RX filter 674 coupled to an LNA 640c, and an RX filter 676 coupled to an LNA 640d. The output of TX filter 672 and the inputs of RX filters 674 and 676 are coupled to an output of triplexer 670, which is coupled to antenna 692.

In the exemplary design shown in FIG. 6, data transmission and reception for the first antenna as well as diversity data reception for the second antenna are supported via antenna interface circuit 650 and primary antenna 690. Data transmission and reception for the second antenna as well as diversity data reception for the first antenna are supported via antenna interface circuit 656 and secondary antenna 692. Antenna-to-antenna isolation between primary antenna 690 and secondary antenna 692 may be exploited to reduce power levels of harmonics and IMD products, which may improve performance.

FIG. 6 shows an exemplary design of using partial multiplexing to support MIMO communication. Partial multiplexing may also be used to support MIMO communication in other manners. A triplexer may be used for each antenna (e.g., as shown in FIG. 6) and may support (i) either contiguous or non-contiguous intra-band CA operation and/or (ii) MIMO operation, without any hardware or implementation change.

The exemplary designs in FIGS. 5A to 5E use a simple triplexer for each of at least one antenna to multiplex one transmit band with two receive bands. The primary antenna may support data transmission on one band A and data reception on two bands A and B (e.g., as shown in FIGS. 5A and 5B). The secondary antenna may support data transmission on one band B and data reception on two bands A and B (e.g., as shown in FIGS. 5A and 5B). For FIGS. 5A and 5B, the outputs of LNAs 540a and 540d may be routed to appropriate receive circuits for band A. The outputs of LNAs 540b and 540c may be routed to appropriate receive circuits for band B.

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Inter-band CA may be better supported with partial multiplexing, e.g., as shown in FIGS. 5A to 5F. For class A1 inter-band CA, it may be easier to match a duplexer (e.g., comprising TX filter 562 and RX filter 564) for band A and RX filter 566 for band B in triplexer 560 than multiplexing two duplexers for bands A and B in a quadplexer. For class A2 inter-band CA, it may be easier to achieve better harmonic and IMD rejection for data transmission on a single band (e.g., as shown in FIG. 5A) as compared to simultaneous data transmissions on two bands band via a quadplexer and a single antenna (e.g., as shown in FIG. 4B). For class A3 inter-band CA, lower insertion loss may be achieved for a triplexer comprising a duplexer and an RX filter (e.g., as shown in FIG. 5A) than two duplexers and a duplexer (e.g., as shown in FIG. 4A), especially when the frequency gap between the two bands is relatively small.

Supporting data transmission on a subset of bands (e.g., on one band) on each antenna via partial multiplexing (e.g., as shown in FIGS. 5A to 5F) may provide various advantages. First, partial multiplexing may support all four classes A1 to A4 of inter-band CA described above. Second, two triplexers 560 and 570 may be used for two antennas, one triplexer for each antenna. Triplexers may be easier to implement and may have lower insertion loss than a quadplexer (e.g., as shown in FIG. 4B) or a combination of two duplexers and a duplexer (e.g., as shown in FIG. 4A). Triplexers may also have a smaller circuit area and fewer part count as compared to the exemplary designs in FIGS. 4A and 4B.

Third, data transmission on different bands via different antennas with partial multiplexing may reduce the power levels of harmonics and IMD products. Active circuits and passive circuits (e.g., switches, duplexers, quadplexers, triplexers, diplexers, PAs, etc.) in a transceiver may inherently have some non-linearity. Simultaneous data transmissions on multiple bands may result in generation of harmonics and IMD products due to non-linearity of circuits in the transceiver. For example, third order intermodulation product (IM3) may result from intermodulation of data transmissions via two transmitters that are present in an RF front-end unit. The IM3 may fall within a receive frequency range and may act as interference that may hinder the ability of a wireless device to receive/detect a desired signal on the downlink, which is commonly referred to as de-sensing. Data transmission and reception simultaneously on two bands via two different antennas may reduce the level of de-sensing IM3. Furthermore, antennas may generate IM3 products due to limited linearity. Separating data transmissions on two bands into two different antennas may mitigate the requirements of an antenna system according to the antenna-to-antenna isolation. In particular, linearity requirements of an antenna may be reduced by an amount that may be dependent on the amount of antenna-to-antenna isolation.

FIGS. 5A to 5F show exemplary design of partial multiplexing to support carrier aggregation on two bands via two antennas. Partial multiplexing may also be used to support carrier aggregation on more than two bands via two antennas.

FIG. 7A show an exemplary design of an RF front-end unit 710 comprising antenna interface circuits 720 and 726 supporting carrier aggregation on three bands A to C via two antennas with diversity reception for all three bands. Antenna interface circuits 720 and 726 may be used for antenna interface circuits 352 and 356, respectively, in FIG. 3. Antenna interface circuit 720 supports data transmission on the uplink on bands A and B and data reception on the downlink on all three bands via a primary antenna 790. Antenna interface

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circuit 726 supports data transmission on the uplink on band C and data reception on the downlink on all three bands via a secondary antenna 792.

In one exemplary design, bands A to C may cover frequency region 1 for LTE/UMTS and may be as follows:

Band A=Band 20 (B20),  
Band B=Band 3 (B3), and  
Band C=Band 7 (B7).

In the exemplary design described above, band A is in low-band, and bands B and C are in high-band. Bands A to C may also correspond to other combinations of bands.

In the exemplary design shown in FIG. 7A, antenna interface circuit 720 includes a duplexer 730 for band A and a triplexer 740 for bands B and C. Duplexer 730 includes a TX filter 732 for band A and an RX filter 734 for band A. The output of TX filter 732 and the input of RX filter 734 are coupled to an output of duplexer 730, which is coupled to a first filter (e.g., a lowpass filter) for band A in a diplexer 738. Triplexer 740 includes a TX filter 742 for band B, an RX filter 744 for band B, and an RX filter 746 for band C. The output of TX filter 742 and the inputs of RX filters 744 and 746 are coupled to an output of triplexer 740, which is coupled to a second filter (e.g., a highpass filter) for bands B and C in diplexer 738. Diplexer 738 is coupled to one input of switches 748. Switches 748 may include other inputs coupled to circuits for other radio technologies, other bands, etc. An output of switches 748 is coupled to primary antenna 790.

In the exemplary design shown in FIG. 7A, antenna interface circuit 726 includes a quadplexer 750 for bands A to C. Quadplexer 750 includes a TX filter 752 for band C, an RX filter 754 for band C, an RX filter 756 for band A, and an RX filter 758 for band B. The output of TX filter 752 and the inputs of RX filters 754 to 758 are coupled to an output of quadplexer 750, which is coupled to one input of switches 768. Other inputs of switches 768 may be coupled to circuits for other radio technologies, other bands, etc. An output of switches 768 is coupled to secondary antenna 792.

FIG. 7B show an exemplary design of an RF front-end unit 712 comprising antenna interface circuits 722 and 728 supporting carrier aggregation on four bands A to D via two antennas with diversity reception for all four bands. Antenna interface circuits 722 and 728 may be used for antenna interface circuits 352 and 356, respectively, in FIG. 3. Antenna interface circuit 722 supports data transmission on the uplink on bands A and C and data reception on the downlink on all four bands via primary antenna 790. Antenna interface circuit 728 supports data transmission on the uplink on bands B and D and data reception on the downlink on all four bands via secondary antenna 792.

In one exemplary design, bands A to D may cover frequency region 1 for LTE/UMTS and may be as follows:

Band A=Band 8 (B8),  
Band B=Band 20 (B20),  
Band C=Band 3 (B3), and  
Band D=Band 7 (B7).

In the exemplary design described above, bands A and B are in low-band, and bands C and D are in high-band. Bands A to D may also correspond to other combinations of bands.

In the exemplary design shown in FIG. 7B, antenna interface circuit 722 includes a triplexer 731 for bands A and B and a triplexer 741 for bands C and D. Triplexer 731 includes a TX filter 733 for band A, an RX filter 735 for band A, and an RX filter 737 for band B. The output of TX filter 733 and the inputs of RX filters 735 and 737 are coupled to an output of triplexer 731, which is coupled to an input of switches 739. Triplexer 741 includes a TX filter 743 for band C, an RX filter 745 for band C, and an RX filter 747 for band D. The output

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of TX filter **743** and the inputs of RX filters **745** and **747** are coupled to an output of triplexer **741**, which is coupled to an input of switches **749**. The output of switches **739** is coupled to a first filter (e.g., a lowpass filter) for bands A and B in a diplexer **779**. The output of switches **749** is coupled to a second filter (e.g., a highpass filter) for bands C and D in diplexer **779**. Diplexer **779** is coupled to primary antenna **790**. Switches **739** and **749** may also couple to circuits for other radio technologies, other bands, etc.

In the exemplary design shown in FIG. 7B, antenna interface circuit **728** includes a triplexer **751** for bands A and B and a triplexer **761** for bands C and D. Triplexer **751** includes a TX filter **753** for band B, an RX filter **755** for band B, and an RX filter **757** for band A. The output of TX filter **753** and the inputs of RX filters **755** and **757** are coupled to an output of triplexer **751**, which is coupled to an input of switches **759**. Triplexer **761** includes a TX filter **763** for band D, an RX filter **765** for band D, and an RX filter **767** for band C. The output of TX filter **763** and the inputs of RX filters **765** and **767** are coupled to an output of triplexer **761**, which is coupled to an input of switches **769**. The output of switches **759** is coupled to a first filter for bands A and B in a diplexer **789**. The output of switches **769** is coupled to a second filter for bands C and D in diplexer **789**. Diplexer **789** is coupled to secondary antenna **792**. Switches **759** and **769** may also couple to circuits for other radio technologies, other bands, etc.

FIGS. 8A and 8B show an exemplary design of an RF front-end unit **810** comprising antenna interface circuits **820** and **826** supporting carrier aggregation on four bands A to D via two antennas with diversity reception for all four bands. Antenna interface circuit **820** in FIG. 8A may be used for antenna interface circuit **350** in FIG. 3, and antenna interface circuit **826** in FIG. 8B may be used for antenna interface circuit **356** in FIG. 3. Antenna interface circuit **820** supports data transmission on the uplink on bands A and C and data reception on the downlink on all four bands via a primary antenna **890**. Antenna interface circuit **826** supports data transmission on the uplink on bands B and D and data reception on the downlink on all four bands via a secondary antenna **892**.

In one exemplary design, bands A to D may cover frequency region 1 for LTE/UMTS and may be as follows:

Band A=Band 7 (B7),  
Band B=Band 3 (B3),  
Band C=Band 20 (B20), and  
Band D=Band 8 (B8).

In the exemplary design described above, bands A and B are in high-band, and bands C and D are in low-band.

In another exemplary design, bands A to D may correspond to the following bands:

Band A=Band 5 (B5),  
Band B=Band 17 (B17),  
Band C=Band 4 (B4), and  
Band D=Band 2 (B2).

Bands A to D may also correspond to other combinations of bands.

In the exemplary design shown in FIG. 8A, antenna interface circuit **820** includes a triplexer **830** for bands A and B, a triplexer **840** for bands C and D, a diplexer **838**, and switches **848**. Triplexer **830** includes a TX filter **832** for band A, an RX filter **834** for band A, and an RX filter **836** for band B. The output of TX filter **832** and the inputs of RX filters **834** and **836** are coupled to an output of triplexer **830**, which is coupled to a first filter (e.g., a highpass filter) for bands A and B in diplexer **838**. Triplexer **840** includes a TX filter **842** for band C, an RX filter **844** for band C, and an RX filter **846** for band D. The output of TX filter **842** and the inputs of RX

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filters **844** and **846** are coupled to an output of triplexer **840**, which is coupled to a second filter (e.g., a lowpass filter) for bands C and D in diplexer **838**. Diplexer **838** is coupled to one input of switches **848**. Switches **848** may include other inputs coupled to circuits for other radio technologies, other bands, etc. An output of switches **848** is coupled to primary antenna **890**.

In the exemplary design shown in FIG. 8B, antenna interface circuit **826** includes a triplexer **850** for bands A and B, a triplexer **860** for bands C and D, a diplexer **858**, and switches **868**. Triplexer **850** includes a TX filter **852** for band B, an RX filter **854** for band B, and an RX filter **856** for band A. The output of TX filter **852** and the inputs of RX filters **854** and **856** are coupled to an output of triplexer **850**, which is coupled to diplexer **858**. Triplexer **860** includes a TX filter **862** for band D, an RX filter **864** for band D, and an RX filter **866** for band C. The output of TX filter **862** and the inputs of RX filters **864** and **866** are coupled to an output of triplexer **860**, which is coupled to diplexer **858**. Diplexer **858** is coupled to one input of switches **868**. Other inputs of switches **868** may be coupled to circuits for other radio technologies, other bands, etc. An output of switches **868** is coupled to secondary antenna **892**.

The exemplary design in FIGS. 8A and 8B may provide various advantages. First, it may be easier to implement triplexers **830**, **840**, **850** and **860** than quadruplexers with lower insertion loss. Second, power levels of harmonics and IMD products of different combinations of bands A and B (e.g., Bands 7 and 3), bands A and D (e.g., Bands 7 and 8), bands B and C (e.g., Bands 3 and 20), and bands C and D (e.g., Bands 20 and 8) may be significantly lower with partial multiplexing. Third, triplexers **830**, **840**, **850** and **860** do not impact the performance of other radio technologies since filters for the second other radio technologies may be coupled directly to switches **848** and **868** and hence would not observe additional insertion loss.

FIGS. 9A and 9B show an exemplary design of an RF front-end unit **910** comprising antenna interface circuits **920** and **926** supporting carrier aggregation on six bands A to F via two antennas with diversity reception for all six bands. Antenna interface circuit **920** in FIG. 9A may be used for antenna interface circuit **350** in FIG. 3, and antenna interface circuit **926** in FIG. 9B may be used for antenna interface circuit **356** in FIG. 3. Antenna interface circuit **920** supports data transmission on the uplink on bands A, C and D and data reception on the downlink on all six bands via a primary antenna **990**. Antenna interface circuit **926** supports data transmission on the uplink on bands B, E and F and data reception on the downlink on all six bands via a secondary antenna **992**.

In one exemplary design, bands A to F may cover frequency regions 2 and 3 for LTE/UMTS and may be as follows:

Band A=Band 1 and/or Band 4 (B1/B4),  
Band B=Band 7 (B7),  
Band C=Band 2 and/or Band 3 (B2/B3),  
Band D=Band 5 (B5),  
Band E=Band 8 (B8), and  
Band F=Band 12, Band 13, and/or Band 17 (B12/B13/B17).

In the exemplary design given above, bands A, B and C are in high-band, and bands D, E and F are in low-band. Bands A to F may also correspond to other combinations of bands.

In the exemplary design shown in FIG. 9A, antenna interface circuit **920** includes a triplexer **930** for bands A and B, a triplexer **940** for bands B and C, a quadruplexer **950** for bands D, E and F, switches **938**, and a diplexer **948**. Triplexer **930**

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includes a TX filter **932** for band A, an RX filter **934** for band A, and an RX filter **936** for band B. The output of TX filter **932** and the inputs of RX filters **934** and **936** are coupled to an output of triplexer **930**, which is coupled to a first input of switches **938**. Triplexer **940** includes a TX filter **942** for band C, an RX filter **944** for band C, and an RX filter **946** for band B. The output of TX filter **942** and the inputs of RX filters **944** and **946** are coupled to an output of triplexer **940**, which is coupled to a second input of switches **938**. Switches **938** may include other inputs coupled to circuits for other radio technologies, other bands, etc. Switches **938** also include an output coupled to a first filter (e.g., a highpass filter) for bands A, B and C in diplexer **948**. Quadplexer **950** includes a TX filter **952** for band D, an RX filter **954** for band D, an RX filter **956** for band E, and an RX filter **958** for band F. The output of TX filter **952** and the inputs of RX filters **954**, **956** and **958** are coupled to an output of quadplexer **950**, which is coupled to a second filter (e.g., a lowpass filter) for bands D, E and F in diplexer **948**. Diplexer **948** is coupled to primary antenna **990**.

In the exemplary design shown in FIG. 9B, antenna interface circuit **926** includes a triplexer **960** for bands D and E, a triplexer **970** for bands D and F, a quadplexer **980** for bands A, B and C, switches **968**, and a diplexer **978**. Triplexer **960** includes a TX filter **962** for band E, an RX filter **964** for band E, and an RX filter **966** for band D. The output of TX filter **962** and the inputs of RX filters **964** and **966** are coupled to an output of triplexer **960**, which is coupled to a first input of switches **968**. Triplexer **970** includes a TX filter **972** for band F, an RX filter **974** for band F, and an RX filter **976** for band D. The output of TX filter **972** and the inputs of RX filters **974** and **976** are coupled to an output of triplexer **970**, which is coupled to a second input of switches **968**. Switches **968** may include other inputs coupled to circuits for other radio technologies, other bands, etc. Switches **968** also include an output coupled to a first filter (e.g., a lowpass filter) for bands D, E and F in diplexer **978**. Quadplexer **980** includes a TX filter **982** for band B, an RX filter **984** for band B, an RX filter **986** for band A, and an RX filter **988** for band C. The output of TX filter **982** and the inputs of RX filters **984**, **986** and **988** are coupled to an output of quadplexer **980**, which is coupled to a second filter (e.g., a highpass filter) for bands A, B and C in diplexer **978**. Diplexer **978** is coupled to secondary antenna **992**.

FIG. 10 shows an exemplary design of an RF front-end unit **1010** comprising an antenna interface circuit **1020** supporting carrier aggregation on six bands A to F. Antenna interface circuit **1020** supports data transmission on the uplink and data reception on the downlink on all six bands via primary antenna **1090**. Another antenna interface circuit may be used for a secondary antenna and may be implemented in similar manner as antenna interface circuit **1020**.

In one exemplary design, bands A to F may correspond to the following bands:

- Band A=Band 13 (B13),
- Band B=Band 9 (B9),
- Band C=Band 20 (B20),
- Band D=Band 4 (B4),
- Band E=Band 3 (B3), and
- Band F=Band 7 (B7).

Bands A to F may also correspond to other combinations of bands.

In the exemplary design shown in FIG. 10, antenna interface circuit **1020** includes a diplexer **1030** for band A, a quadplexer **1040** for bands B and C, a diplexer **1050** for band D, a quadplexer **1060** for bands E and F, switches **1038** and **1058**, and a diplexer **1070**. Diplexer **1030** includes a TX filter **1032** for band A and an RX filter **1034** for band A. The output

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of TX filter **1032** and the input of RX filter **1034** are coupled to an output of diplexer **1030**, which is coupled to a first input of switches **1038**. Quadplexer **1040** includes a TX filter **1042** for band B, an RX filter **1044** for band B, a TX filter **1046** for band C, and an RX filter **1048** for band C. The outputs of TX filters **1042** and **1046** and the inputs of RX filters **1044** and **1048** are coupled to an output of quadplexer **1040**, which is coupled to a second input of switches **1038**. Switches **1038** may include other inputs coupled to circuits for other radio technologies, other bands, etc. Switches **1038** also includes an output coupled to a first filter (e.g., a lowpass filter) for bands A, B and C in diplexer **1070**.

Diplexer **1050** includes a TX filter **1052** for band D and an RX filter **1054** for band D. The output of TX filter **1052** and the input of RX filter **1054** are coupled to an output of diplexer **1050**, which is coupled to a first input of switches **1058**. Quadplexer **1060** includes a TX filter **1062** for band E, an RX filter **1064** for band E, a TX filter **1066** for band F, and an RX filter **1068** for band F. The outputs of TX filters **1062** and **1066** and the inputs of RX filters **1064** and **1068** are coupled to an output of quadplexer **1060**, which is coupled to a second input of switches **1058**. Switches **1058** may include other inputs coupled to circuits for other radio technologies, other bands, etc. Switches **1058** also includes an output coupled to a second filter (e.g., a highpass filter) for bands D, E and F in diplexer **1070**.

In an exemplary design, an apparatus (e.g., a wireless device, an IC, a circuit module, etc.) may comprise first and second antenna interface circuits. The first antenna interface circuit (e.g., antenna interface circuit **550** in FIG. 5A) may comprise a first TX filter (e.g., TX filter **562**) for a first band. The first TX filter may filter a first RF signal prior to transmission via a first antenna (e.g., primary antenna **590**). The second antenna interface circuit (e.g., antenna interface circuit **556** in FIG. 5A) may comprise a second TX filter (e.g., TX filter **572**) for a second band. The second band may be the same as the first band or may be different from the first band. The second TX filter may filter a second RF signal prior to transmission via a second antenna (e.g., secondary antenna **592**). The first and second RF signals may be transmitted simultaneously on the first and second bands to a wireless network. For example, the first and second RF signals may be transmitted simultaneously on first and second carriers, respectively, in the first and second bands for carrier aggregation. The first RF signal may be transmitted on the first band via the first antenna interface circuit and the first antenna. The second RF signal may be transmitted on the second band via the second antenna interface circuit and the second antenna.

The second band may be different from the first band. In an exemplary design, the first and second bands may be in the same band group, which may be low-band, or mid-band, or high-band. In another exemplary design, the first and second bands may be in different band groups, e.g., low-band and mid-band, or low-band and high-band, or mid-band and high-band.

In an exemplary design shown in FIG. 5A, the first antenna interface circuit may comprise a first triplexer (e.g., triplexer **560**) including the first TX filter for the first band, a first RX filter (e.g., RX filter **564**) for the first band, and a second RX filter (e.g., RX filter **566**) for the second band. The second antenna interface circuit may comprise a second triplexer (e.g., triplexer **570**) including the second TX filter for the second band, a third RX filter (e.g., RX filter **574**) for the second band, and a fourth RX filter (e.g., RX filter **576**) for the first band.

In one exemplary design, which is shown in FIG. 5A, each antenna may support primary RX for one band and diversity

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RX for another band. The first RX filter may be configured as primary downlink for the first band, and the second RX filter may be configured as diversity downlink for the second band. The third RX filter may be configured as primary downlink for the second band, and the fourth RX filter may be configured as diversity downlink for the first band.

In another exemplary design, which shown in FIG. 5B, the primary antenna may support primary downlink for both bands, and the secondary antenna may support diversity downlink for both bands. The first RX filter may be configured as primary downlink for the first band, and the second RX filter may be configured as primary downlink for the second band. The third RX filter may be configured as diversity downlink for the second band, and the fourth RX filter may be configured as diversity downlink for the first band.

In another exemplary design shown in FIG. 5F, the first antenna interface circuit may comprise a duplexer (e.g., duplexer 561) including the first TX filter and an RX filter for the first band. Alternatively or additionally, the second antenna interface circuit may comprise a duplexer (e.g., duplexer 571 in FIGS. 5D and 5F) including the second TX filter and an RX filter for the second band.

In one exemplary design, a lowpass filter (e.g., lowpass filter 568 in FIG. 5C) may be coupled to the first TX filter. The lowpass filter may filter the first RF signal and attenuate at least one harmonic (e.g., a third harmonic) of the first RF signal. The first RF signal may be sent in the first band, but a harmonic of the first RF signal may fall within a receive frequency range of the second band. The lowpass filter may attenuate this harmonic of the first RF signal, which may improve performance of data reception.

In another exemplary design shown in FIG. 8A, the first antenna interface circuit may comprise first and second triplexers. The first triplexer (e.g., triplexer 830 in FIG. 8A) may include the first TX filter for the first band, a first RX filter (e.g., RX filter 834) for the first band, and a second RX filter (e.g., RX filter 836) for the second band. The second triplexer (e.g., triplexer 840) may include a third TX filter (e.g., TX filter 842) for a third band, a third RX filter (e.g., RX filter 844) for the third band, and a fourth RX filter (e.g., RX filter 846) for a fourth band. The first antenna interface circuit may further comprise a diplexer and at least one switch. The diplexer (e.g., diplexer 838) may be coupled between the first and second triplexers and the first antenna. The at least one switch (e.g., switches 848) may be coupled between the diplexer and the first antenna.

In the exemplary design shown in FIG. 8B, the second antenna interface circuit may comprise third and fourth triplexers. The third triplexer (e.g., triplexer 850 in FIG. 8B) may include the second TX filter (e.g., TX filter 852) for the second band, a fifth RX filter (e.g., RX filter 854) for the second band, and a sixth RX filter (e.g., RX filter 856) for the first band. The fourth triplexer (e.g., triplexer 860) may include a fourth TX filter (e.g., TX filter 860) for the fourth band, a seventh RX filter (e.g., RX filter 864) for the fourth band, and an eighth RX filter (e.g., RX filter 866) for the third band. The second antenna interface circuit may further comprise a diplexer (e.g., diplexer 858) and at least one switch (e.g., switches 868) coupled between the third and fourth triplexers and the second antenna.

In yet another exemplary design shown in FIG. 9A, the first antenna interface circuit may comprise first, second and third multiplexers. The first multiplexer (e.g., triplexer 930 in FIG. 9A) may include the first TX filter and a first RX filter (e.g., RX filter 934) for the first band. The second multiplexer (e.g., triplexer 940) may include a third TX filter (e.g., TX filter 942) and a second RX filter (e.g., RX filter 944) for a third

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band. The third multiplexer (e.g., quadplexer 950) may include a fourth TX filter (e.g., TX filter 952) and a third RX filter (e.g., RX filter 954) for a fourth band. The first antenna interface circuit may further comprise (i) at least one switch (e.g., switches 938) coupled to the first and second multiplexers and (ii) a diplexer (e.g., diplexer 948) coupled to the at least one switch, the third multiplexer, and the first antenna. The first, second, and third multiplexers may comprise additional TX filters and/or RX filters, e.g., as shown in FIG. 9A.

In the exemplary design shown in FIG. 9B, the second antenna interface circuit may comprise fourth, fifth, and sixth multiplexers. The fourth multiplexer (e.g., triplexer 960 in FIG. 9B) may include the second TX filter (e.g., TX filter 962) and a fourth RX filter (e.g., RX filter 964) for the second band. The fifth multiplexer (e.g., triplexer 970) may include a fifth TX filter (e.g., TX filter 972) and a fifth RX filter (e.g., RX filter 974) for a fifth band. The sixth multiplexer (e.g., quadplexer 980) may include a sixth TX filter (e.g., TX filter 982) and a sixth RX filter (e.g., RX filter 984) for a sixth band. The fourth, fifth, and sixth multiplexers may comprise additional TX filters and/or RX filters, e.g., as shown in FIG. 9B.

In an exemplary design, the first antenna may be isolated from the second antenna by at least a target antenna-to-antenna isolation, which may be 15 dB or some other value. The antenna-to-antenna isolation may provide various advantages described above (e.g., reduced power levels of harmonics and IMD products) when the first and second RF signals are transmitted simultaneously on different bands via different antennas for carrier aggregation.

In another exemplary design, an apparatus (e.g., a wireless device, an IC, a circuit module, etc.) may comprise a triplexer and a multiplexer. The triplexer may be operatively coupled to a first antenna and may comprise a first TX filter for a first band, a first RX filter for the first band, and a second RX filter for a second band. The second band is different from the first band. The multiplexer may be operatively coupled to a second antenna and may comprise a second TX filter for the second band and a third RX filter for the first band. The triplexer and the multiplexer may support communication (e.g., with a single wireless network) on one or both of the first and second bands.

In an exemplary design, the multiplexer may be a triplexer and may include the second TX filter for the second band, the third RX filter for the first band, and a fourth RX filter for the second band. In another exemplary design, the multiplexer may be a diplexer, or a quadplexer, or some other circuit.

In an exemplary design, the triplexer and the multiplexer may support carrier aggregation on the downlink and may receive downlink data transmissions sent simultaneously on the first and second bands. In another exemplary design, the triplexer and the multiplexer may support carrier aggregation on the uplink and may simultaneously send (i) a first uplink data transmission on the first band via the first antenna and (ii) a second uplink data transmission on the second band via the second antenna for carrier aggregation. In yet another exemplary design, the triplexer may send an uplink data transmission on the first band via the first antenna without carrier aggregation.

FIG. 11 shows an exemplary design of a process 1100 for supporting carrier aggregation. A first RF signal may be filtered with a first TX filter (e.g., TX filter 562 in FIG. 5A) for a first band prior to transmission via a first antenna (block 1112). A second RF signal may be filtered with a second TX filter (e.g., TX filter 572) for a second band prior to transmission via a second antenna (block 1114). The first and second

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RF signals may be transmitted simultaneously on the first and second bands via the first and second antennas for carrier aggregation.

A third RF signal may be received via the first antenna and may be filtered with a first RX filter (e.g., RX filter **564** in FIG. **5A**) for the first band (block **1116**). A fourth RF signal may be received via the second antenna and may be filtered with a second RX filter (e.g., RX filter **574**) for the second band (block **1118**). A fifth RF signal may be received via the first antenna and may be filtered with a third RX filter (e.g., RX filter **566**) for the second band (block **1120**). A sixth RF signal may be received via the second antenna and may be filtered with a fourth RX filter (e.g., RX filter **576**) for the first band (block **1122**).

The antenna interface circuits and filters described herein may be implemented on an IC, an analog IC, an RFIC, a mixed-signal IC, an ASIC, a printed circuit board (PCB), an electronic device, etc. The antenna interface circuits and filters may also be fabricated with various technologies. Active circuits in the antenna interface circuits may be fabricated with various IC process technologies such as complementary metal oxide semiconductor (CMOS), N-channel MOS (NMOS), P-channel MOS (PMOS), bipolar junction transistor (BJT), bipolar-CMOS (BiCMOS), silicon germanium (SiGe), gallium arsenide (GaAs), heterojunction bipolar transistors (HBTs), high electron mobility transistors (HEMTs), silicon-on-insulator (SOI), etc.

An apparatus implementing the antenna interface circuits and/or filters described herein may be a stand-alone device or may be part of a larger device. A device may be (i) a stand-alone IC, (ii) a set of one or more ICs that may include memory ICs for storing data and/or instructions, (iii) an RFIC such as an RF receiver (RFR) or an RF transmitter/receiver (RTR), (iv) an ASIC such as a mobile station modem (MSM), (v) a module that may be embedded within other devices, (vi) a receiver, cellular phone, wireless device, handset, or mobile unit, (vii) etc.

In one or more exemplary designs, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

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The previous description of the disclosure is provided to enable any person skilled in the art to make or use the disclosure. Various modifications to the disclosure will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other variations without departing from the scope of the disclosure. Thus, the disclosure is not intended to be limited to the examples and designs described herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

What is claimed is:

1. An apparatus comprising:

a first antenna interface circuit comprising a first transmit (TX) filter for a first band, the first TX filter configured to filter a first radio frequency (RF) signal prior to transmission via a first antenna; and

a second antenna interface circuit comprising a second TX filter for a second band, the second TX filter configured to filter a second RF signal prior to transmission via a second antenna, the first and second TX filters configured to filter the first and second RF signals sent simultaneously on the first and second bands to a wireless network, and at least one of the first and second antenna interface circuits including a receive (RX) filter for the first band, and another RX filter for the second band, the RX filter and the another RX filter receiving on a common antenna, the first and second bands configured for carrier aggregation.

2. The apparatus of claim 1, the first and second RF signals being sent simultaneously on first and second carriers, respectively, for carrier aggregation.

3. The apparatus of claim 1, the first antenna interface circuit comprising a first triplexer including the first TX filter for the first band, a first receive (RX) filter for the first band, and a second RX filter for the second band.

4. The apparatus of claim 3, the second antenna interface circuit comprising a second triplexer including the second TX filter for the second band, a third RX filter for the second band, and a fourth RX filter for the first band.

5. The apparatus of claim 3, the first antenna interface circuit further comprising a duplexer including a third TX filter for the third band and a third RX filter for the third band.

6. The apparatus of claim 1, the first antenna interface circuit comprising a duplexer including the first TX filter and a receive (RX) filter for the first band.

7. The apparatus of claim 1, the second antenna interface circuit comprising a duplexer including the second TX filter and a receive (RX) filter for the second band.

8. The apparatus of claim 1, the first antenna interface circuit comprising a quadplexer including the first TX filter for the first band, a first receive (RX) filter for the first band, a third TX filter for a third band, and a second RX filter for the third band.

9. The apparatus of claim 1, the first antenna interface circuit comprising a lowpass filter coupled to the first TX filter and configured to filter the first RF signal and attenuate at least one harmonic of the first RF signal.

10. The apparatus of claim 1, the first antenna interface circuit comprising:

a first triplexer including the first TX filter for the first band, a first receive (RX) filter for the first band, and a second RX filter for the second band; and

a second triplexer including a third TX filter for a third band, a third RX filter for the third band, and a fourth RX filter for a fourth band.

11. The apparatus of claim 10, the second antenna interface circuit comprising:



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- a third triplexer including the second TX filter for the second band, a fifth RX filter for the second band, and a sixth RX filter for the first band; and
- a fourth triplexer including a fourth TX filter for the fourth band, a seventh RX filter for the fourth band, and an eighth RX filter for the third band.
12. The apparatus of claim 10, the first antenna interface circuit further comprising a diplexer coupled between the first and second triplexers and the first antenna.
13. The apparatus of claim 12, the first antenna interface circuit further comprising at least one switch coupled between the diplexer and the first antenna.
14. The apparatus of claim 1, further comprising:  
at least one switch coupled between the first TX filter and the first antenna, the first TX filter being used for a first radio technology; and  
at least one filter for a second radio technology coupled to the at least one switch.
15. The apparatus of claim 1, the first antenna interface circuit comprising:  
a first multiplexer including the first TX filter and a first receive (RX) filter for the first band;  
a second multiplexer including a third TX filter and a second RX filter for a third band; and  
a third multiplexer including a fourth TX filter and a third RX filter for a fourth band.
16. The apparatus of claim 15, the first antenna interface circuit further comprising:  
at least one switch coupled to the first and second multiplexers; and  
a diplexer coupled to the at least one switch, the third multiplexer, and the first antenna.
17. An apparatus comprising:  
a triplexer operatively coupled to a first antenna and comprising a first transmit (TX) filter for a first band, a first receive (RX) filter for the first band, and a second RX filter for a second band, the first RX filter and the second RX filter receiving on the first antenna, the first and second bands configured for carrier aggregation; and  
a multiplexer operatively coupled to a second antenna and comprising a second TX filter for the second band and a third RX filter for the first band.
18. The apparatus of claim 17, the multiplexer comprising a second triplexer and including the second TX filter for the second band, the third RX filter for the first band, and a fourth RX filter for the second band.
19. The apparatus of claim 17, the triplexer and the multiplexer configured to receive downlink data transmissions sent simultaneously on the first and second bands for carrier aggregation.
20. The apparatus of claim 17, the triplexer and the multiplexer configured to simultaneously send a first uplink data transmission on the first band via the first antenna and a second uplink data transmission on the second band via the second antenna for carrier aggregation.

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21. The apparatus of claim 17, the triplexer configured to send an uplink data transmission on the first band via the first antenna without carrier aggregation.
22. A method comprising:  
filtering in a first antenna interface circuit a first radio frequency (RF) signal with a first transmit (TX) filter for a first band prior to transmission via a first antenna; and  
filtering in a second antenna interface circuit a second RF signal with a second TX filter for a second band prior to transmission via a second antenna, the first and second RF signals being transmitted simultaneously on the first and second bands for carrier aggregation, and at least one of the first and second antenna interface circuits including a receive (RX) filter for the first band, and another RX filter for the second band, the RX filter and the another RX filter receiving on a common antenna, the first and second bands configured for carrier aggregation.
23. The method of claim 22, further comprising:  
filtering a third RF signal, received via the first antenna, with a first receive (RX) filter for the first band; and  
filtering a fourth RF signal, received via the second antenna, with a second RX filter for the second band.
24. The method of claim 23, further comprising:  
filtering a fifth RF signal, received via the first antenna, with a third RX filter for the second band; and  
filtering a sixth RF signal, received via the second antenna, with a fourth RX filter for the first band.
25. An apparatus comprising:  
means for filtering in a first antenna interface circuit a first radio frequency (RF) signal for a first band prior to transmission via a first antenna; and  
means for filtering in a second antenna interface circuit a second RF signal for a second band prior to transmission via a second antenna, the first and second RF signals being transmitted simultaneously on the first and second bands for carrier aggregation, and at least one of the first and second antenna interface circuits including a receive (RX) filter for the first band, and another RX filter for the second band, the RX filter and the another RX filter receiving on a common antenna, the first and second bands configured for carrier aggregation.
26. The apparatus of claim 25, further comprising:  
means for filtering a third RF signal, received via the first antenna, for the first band; and  
means for filtering a fourth RF signal, received via the second antenna, for the second band.
27. The apparatus of claim 26, further comprising:  
means for filtering a fifth RF signal, received via the first antenna, for the second band; and  
means for filtering a sixth RF signal, received via the second antenna, for the first band.

\* \* \* \* \*